# JOURNAL of THE IRON AND STEEL INSTITUTE

VOL. 157 PART 2

OCTOBER 1947

Editor . . K. HEADLAM-MORLEY
Technical Editor . . A. E. CHATTIN, B.Sc. (Hons. Met.) A.R.I.C., F.I.M.
Managing Editor . E. R. MORT, B.Sc., F.I.M.
Assistant Editor . . C. R. HARMAN, B.Sc. (Eng.)

PUBLISHED MONTHLY

Editorial contents copyright by THE IRON AND STEEL INSTITUTE

EDITORIAL AND ADVERTISEMENT OFFICES
4, Grosvenor Gardens, London, S.W.1
Telephone : SLOane 0061
Telegrams : Irosamente, Sowest, London

SUBSCRIPTIONS
Members : Free
Extra Copies 7s. 6d. each
Non-Members : £5 . 0 . 0 per annum
Single Copies 10s. each

NOTE : The Institute as a body is not responsible for statements made, or opinions expressed, in papers, articles or discussion appearing in the Journal of the Iron and Steel Institute.

## CONTENTS

**IRON AND STEEL INSTITUTE PAPERS**

"The Breadths of X-ray Diffraction Lines from Martensite" *by J. A. Wheeler and M. A. Jaswon* .. 161
"The Mechanism of Carbon Removal in the Open-Hearth Furnace" *by the late A. H. Jay* .. 167
"Some Aspects of the Refining of High-Phosphorus Iron" *by W. L. Kerlie* 173
"A Note on Variations in Producer-Gas Quality" *by J. E. de Graaf* .. 183

**DISCUSSION ON PAPERS**

Correspondence on Papers presented at the Spring Meeting, 1947 .. .. 191

**BRITISH IRON AND STEEL RESEARCH ASSOCIATION**

"An Introduction to the Interaction of Carbon and Iron Ore at Temperatures up to 1450° C." *by H. L. Saunders and H. J. Tress* .. .. .. 215
"Brittle Fracture in Mild-Steel Plates" *by W. Barr and Constance F. Tipper* .. .. .. .. .. .. .. .. .. .. 223
"Effect of the Manganese/Carbon Ratio on the Brittle Fracture of Mild Steel" *by W. Barr and A. J. K. Honeyman* .. .. .. .. .. 239
"Some Factors Affecting the Notched-Bar Impact Properties of Mild Steel" *by W. Barr and A. J. K. Honeyman* .. .. .. .. .. 243

**IRON AND STEELWORKS ENGINEERING**

"Modern Small Rolling Mills" *by G. A. Phipps* .. .. .. .. 247
"Mechanical and Electrical Features of Primary Hot-Rolling-Mill Auxiliaries"
Sect. I—"Mechanical Features" *by W. W. Franklin* .. .. .. 262
Sect. II—"Electrical Features" *by P. F. Grove* .. .. .. .. 272

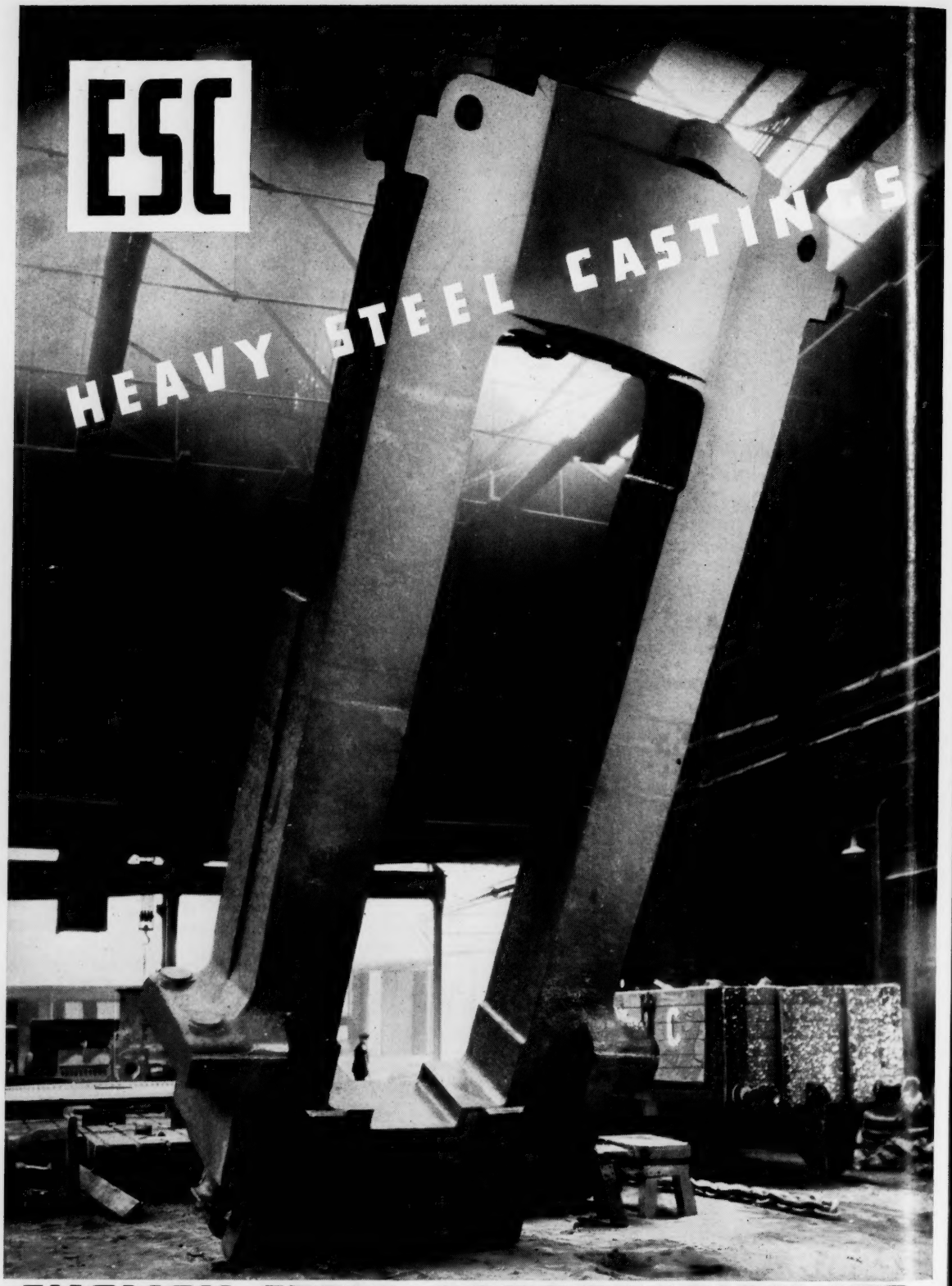
**NEWS**

Iron and Steel Institute—Meetings .. .. .. .. .. .. 279
Information Department .. .. .. .. .. .. .. 280
News of Members .. .. .. .. .. .. .. .. 281
Iron and Steel Engineers Group .. .. .. .. .. .. 284
British Iron and Steel Research Association .. .. .. .. .. 284
Institution of Metallurgists .. .. .. .. .. .. .. 285
Affiliated Local Societies .. .. .. .. .. .. .. 285
News of Science and Industry .. .. .. .. .. .. .. 286
Translations .. .. .. .. .. .. .. .. .. 288

**ABSTRACTS and BOOK NOTICES**

Contents .. .. .. .. .. .. .. .. .. .. 289
Abstracts .. .. .. .. .. .. .. .. .. 289–319
Book Notices .. .. .. .. .. .. .. .. .. 319
New Publications .. .. .. .. .. .. .. .. .. 320

*Correspondence on Papers published in this issue should be submitted to the Editor before 20th December, 1947*




ENGLISH STEEL CORPORATION LTD

VICKERS WORKS SHEFFIELD

## MR. JAMES SINCLAIR KERR, O.St.J., F.I.M., F.Inst.F.

JAMES SINCLAIR KERR, Assistant Managing Director of the Lancashire Steel Corporation, Ltd., Warrington, and Resident and Technical Director at the Irlam Works of the Lancashire Steel Corporation, Ltd., Irlam, near Manchester, has been closely connected with the iron and steel industry for over 35 years, and has a very wide experience of coke ovens, blast-furnaces, steelplants, and rolling mills, etc., both in Great Britain and abroad.

Mr. Sinclair Kerr's initial technical and operating experience was obtained in the Blast-Furnace and Open-Hearth Departments at the works of Messrs. Palmers Shipbuilding and Iron Co., Ltd., Jarrow-on-Tyne, and he was appointed Manager of the Steel Plant in 1911. In 1912 he became Steelworks Manager at Messrs. Bolckow Vaughan and Co., Ltd., operating the acid Bessemer, basic Bessemer, and duplex processes. As he developed the straight open-hearth furnace, the acid and basic Bessemer vessels were put out of commission.

Mr. Sinclair Kerr was loaned by his company to start up a steelplant in France, and during this time he gained much technical and operating experience from other works in France, Belgium and Germany. In 1923 he was appointed Works Manager of Messrs. Bolckow Vaughan and Co., Ltd. ; he held this position until 1927 when he left to join the Partington Steel and Iron Co., Ltd., Irlam, near Manchester, as General Manager, being appointed Managing Director in 1928. He assisted very largely in the formation of the Lancashire Steel Corporation, Ltd., and the Wigan Coal Corporation, Ltd., and was responsible for reconstruction work at the Irlam Works. In 1936 he was appointed Chairman and Operating Director of Messrs. Wm. Robertson, Ltd., Letchford, near Warrington, and reorganized the company. He is also a Director of the Pearson and Knowles Engineering Co., Ltd., Messrs. Rylands Bros., Ltd., the Whitecross Co., Ltd. (co-Chairman), and the Wigan Coal Corporation, Ltd.

Mr. Sinclair Kerr, who gained the Silver Medal and Goldsmith's Prize for iron and steel manufacture, is a Founder Fellow and Member of Council of the Institution of Metallurgists, on which he represents the Council of the Iron and Steel Institute. He is also a member of the Grand Council of the Federation of British Industries, and a member of a large number of committees of other important bodies, including the British Iron and Steel Federation, the Iron and Steel Control, the British Iron and Steel Research Association, and the British Standards Institution. He joined the Iron and Steel Institute in 1911 and was elected a Member of Council in 1939; he represents the Council on several technical organizations. He is the author of a number of papers on steelmaking and fuel economy. Great importance is attached by Mr. Sinclair Kerr to the teaching of accident prevention in the iron and steel industry. In 1936 he received the decoration of Officer of the Venerable Order of the Hospital of St. John of Jerusalem.

**James Sinclair Kerr, Esq., O.St.J., F.I.M., F.Inst.F.**
**Member of Council.**

IRON AND STEEL
INSTITUTE PAPERS

PLANT DESIGN · MANUFACTURE · RESEARCH · DEVELOPMENT

# The Breadths of X-Ray Diffraction Lines from Martensite*

*By J. A. Wheeler, Ph.D.,† and M. A. Jaswon, B.A., B.Sc.†*

SYNOPSIS

*The variation with Bragg angle of the breadths of X-ray diffraction lines from martensite has been investigated experimentally, using the Jones' method of correction for instrumental broadening. The results indicate that the line broadening of martensite is due to balanced internal stresses rather than to small particles.*

## INTRODUCTION

THE extreme diffuseness of the X-ray diffraction lines obtained from martensite has frequently been attributed to the existence of a martensitic substructure on a scale sufficiently fine to give rise to "small particle size" effects. Many workers have published estimates of the particle size of martensite on the basis of this assumption,[1, 2] and, more recently, the same view has been accepted in standard reference books covering this field.[3, 4]

Metallurgists have long recognized that the transformation from austenite to martensite gives rise to a pattern of balanced local internal stresses in the resulting structure, and the existence of micro-cracks in quenched steels (the cracked martensite needles so beautifully photographed by Lucas,[5] for example) shows that these stresses may be high. As this stress pattern must itself give rise to a broadening of the X-ray diffraction lines, it seemed possible that the assumption of a fine substructure in martensite was unnecessary; the work reported in the present paper was therefore undertaken to investigate this question and, if possible, to decide whether a microstress explanation could account fully for the experimentally observed line broadening.

## PARTICLE SIZE AND MICROSTRESS BROADENING

There are two possible methods of distinguishing experimentally between line broadening due to small particles and that due to microstresses. They are based on the following considerations:

(1) The relation between $\beta$, the breadth of any line, and $\theta$, the Bragg angle at which it appears. It has been pointed out by Dehlinger and Kochendorfer[6] that if broadening is caused by small particles the line breadth should be proportional to sec $\theta$, whereas if a microstress mechanism is responsible $\beta$ should be proportional to tan $\theta$.

(2) The line breadth is proportional to $\lambda$, the X-ray wavelength, for particle-size broadening, but should be independent of $\lambda$ if broadening is caused by local stresses. This criterion has been used by Wood[7] in his investigations of the line broadening caused by cold work.

A third factor on which the line breadths may depend is the value of Young's modulus for the crystallographic direction perpendicular to the planes which give rise to the reflection, since this will control the change in interplanar spacing for a given stress. This factor must be borne in mind in the interpretation of results, but cannot be used as a criterion of microstress broadening because (*a*) the stress itself might be a function of crystallographic direction, and (*b*) similar effects could be caused by the presence of small particles

* Received 2nd April, 1947.

† Department of Metallurgy, University of Birmingham.



XUM

whose average dimension was a function of crystallographic direction.

In the present work only the first of the above two methods has been used, because the characteristic X-radiations with which measurable photographs of martensite can be obtained cover only a very restricted range of wavelengths ($CoK_\alpha = 1{\cdot}79$ Å., $CrK_\alpha = 2{\cdot}29$ Å.), and the experimental inaccuracy in the determination of line breadths is too great to allow of systematic investigation within such a narrow field.

### *Experimental Procedure*

Experiments have been made with one industrial high-carbon steel (*CA*) and two high-purity iron–carbon alloys (*PB* and *PC*). The latter were made from electrolytic iron (Hilger's No. F. 693) and graphite (Hilger's No. F. 623) which were melted together under hydrogen in a magnesia crucible and allowed to cool *in vacuo*. The ingot *PB* was sectioned immediately and numerous surfaces were examined microscopically, but no evidence of inhomogeneity was found. However, ingot *PC* was homogenized for 48 hours at 1130° C. in an atmosphere of pure nitrogen before X-ray samples were taken.

Rods 1 mm. square and 20 mm. long were cut from all three steels, and on each a length of 15 mm. was turned to 0·5-mm. dia. They were sealed in evacuated silica tubes, heated to 1050° C. for 15 min., and water-quenched to give a martensitic structure.

X-ray photographs of the rods were taken in a 9-cm. Debye-Scherrer camera, using $FeK_\alpha$ radiation and an exposure of 10 m.amp. hr. The rods were then again sealed in evacuated silica tubes, tempered for 20 hr. at 600° C., cooled to room temperature at 1° C./min., and rephotographed under experimental conditions identical with those for the photographs taken in the martensitic condition ; the exposure required for the tempered specimens was 3 m.amp. hr. The purpose of the photographs from the tempered specimens will be discussed in a later section.

Finally the carbon content of each rod was determined by a microcombustion method, the results being as follows :

| Specimen | Carbon, % |
|---|---|
| *CA*1 | 1·35 |
| *CA*2 | 1·35 |
| *PB*2 | 1·43 |
| *PC*1 | 1·35 |

### *Measurement of Line Breadths*

Density determinations were made at intervals of 0·1 mm. along the entire length of all films by means of a Dobson-type microphotometer. From calibration strips recorded on the films by means of a rotating stepped sector it was found that these density figures could be taken as directly proportional to the incident X-ray intensity for the whole range of film densities used.

The intensity distribution curve for each of the martensite lines was deduced by the correction processes described in the next paragraph and illustrated for a typical line by Figs. 1–4. X-ray intensity was first plotted against film distance over the full length of the film to enable the background to be interpolated under each of the peaks with maximum accuracy ; Fig. 1 shows a typical background correction curve. All the lines, including those from the retained austenite, were then replotted separately with background correction, as shown in Fig. 2.

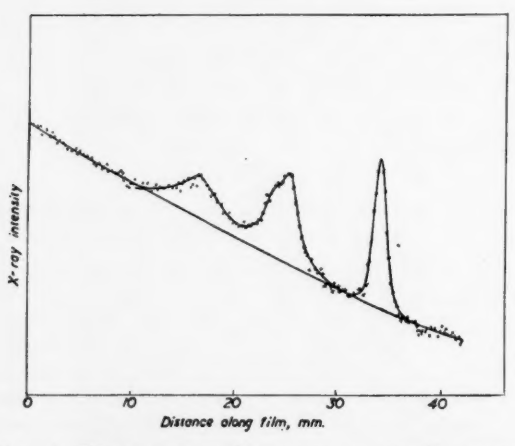



FIG. 1—Photometer readings over an angular range including martensite lines *M*8 and austenite lines *A*11 and *A*12

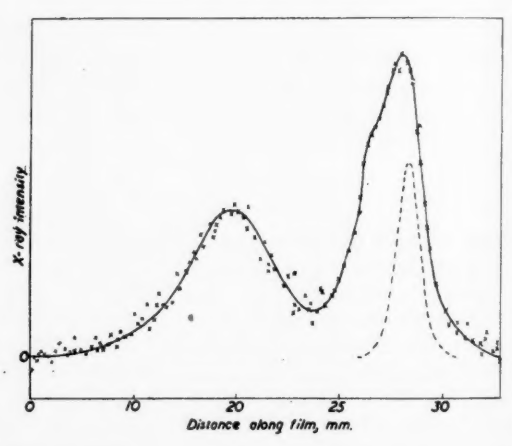



FIG. 2—Photometer curve for lines *M*8 and *A*12 obtained from Fig. 1 after background correction

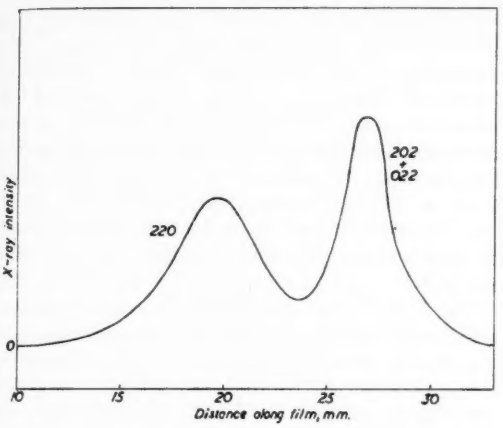



FIG. 3—Curve for lines $M8$ obtained from Fig. 2 by subtracting the calculated intensity distribution curve for line $A12$

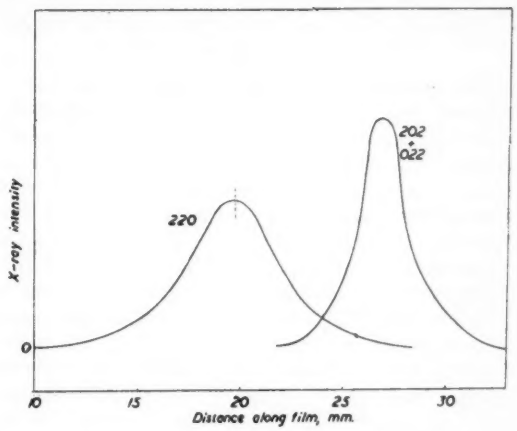



FIG. 4—Separated curves for the two lines $M8$ obtained by symmetrical resolution of the composite curve of Fig. 3

The martensite doublets $M2$ and $M8$ (using the designations adopted by Lipson and Parker[8]) are overlapped by the austenite lines $A3$ and $A12$ respectively. To correct for this, the exact positions of the peaks of these two austenite lines were calculated by extrapolation from measurements on the separate austenite lines $A4$, $A8$, and $A11$, and their intensities evaluated by submitting the measured intensities of lines $A4$ and $A11$, respectively, to the appropriate corrections for multiplicity, atomic scattering power, and the trigonometric and absorption factors. The intensity distribution curves so calculated for lines $A3$ and $A12$ were inserted at the appropriate Bragg angle, as illustrated by the broken curve in Fig. 2, and subtracted from the curve for the composite line, giving the intensity distribution curve for the martensite doublet only (Fig. 3).

The last stage in the correction process is the resolution of the constituent lines of each martensite doublet to give the separated lines shown in Fig. 4. This has been done by the method described by Lipson and Parker,[8] which assumes the symmetry, about its peak, of the component unaffected by the austenite line overlap; the symmetry of the other component has been used as a check on the consistency of this method.

In the analysis of the ferrite lines from the tempered specimens only the first of the above processes, the correction for film background, was required.

The area under the intensity distribution curve for any line was measured using Simpson's approximation, and the integral line breadth calculated from the Laue formula. The mean of the two breadths obtained from opposite sides of the film was recorded as the measured line breadth ($B_0$ for martensite lines, $b_0$ for ferrite lines).

The results obtained from the microphotometry and analysis of the measurements on the two films referring to any one specimen were therefore the breadths and Bragg angles of eight martensite and four ferrite lines. A typical set of results is recorded in Table I.

TABLE I—*Typical Results of Analysis of Film Measurements*

| | Martensite-Line Indices | | | | | | | | Ferrite-Line Indices | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 101+011 | 110 | 002 | 200+020 | 112 | 211+121 | 202+022 | 220 | 110 | 200 | 211 | 220 |
| Bragg angle ... ... | 28·14 | 28·99 | 40·19 | 43·00 | 53·59 | 55·81 | 69·45 | 74·03 | 28·82 | 42·75 | 56·04 | 72·87 |
| Line breadth ($B_0$ martensite lines, $b_0$ ferrite lines), mm. ... ... | 0·849 | 0·823 | 1·358 | 1·538 | 1·889 | 1·934 | 2·933 | 5·061 | 0·388 | 0·442 | 0·581 | 0·901 |

### Determination of Line Broadening from Line-Breadth Measurements

The breadth of an X-ray diffraction line is affected by numerous experimental factors for which correction must be made before the broadening to be attributed to particle-size or microstress effects can be assessed. In the present work the method developed by Jones[9] has been adopted for this correction process. This involves the measurement of the breadths of "standard" lines from an annealed substance of "infinite particle size"* photographed under the same experimental conditions as the substance under investigation. Thus for measurements of the particle size of colloidal gold Jones used a composite specimen containing the powder to be examined and annealed molybdenum powder, in this way recording the standard lines and the lines under investigation simultaneously.

In the present work the necessity of using rod specimens is obvious, since local internal stresses are an issue in the investigation, and so the method of correction adopted has been to use as standards of line breadth the diffraction lines produced by the same rod specimens after tempering to give undistorted ferrite. Ideally the standard substance for the evaluation of the correction for experimental broadening should be stress free *martensite* of infinite particle size, but the error introduced by the use of *ferrite* is likely to be small, since the contribution to the line breadth of martensite by the carbon atoms in supersaturated solid solution is probably negligible.

To apply the correction for instrumental broadening obtained from the measurements on the ferrite lines, the relationship developed by Jones between $\beta/B$ and $b/B$ has been accepted, and values of $\beta$ have been obtained from the measured values of $B$ and $b$ directly from his curve. ($B$, $b$, and $\beta$ have here the same significance as in Jones' paper, *i.e.*, $\beta$ = corrected breadth of the line under investigation, $B$ = measured breadth of the line under investigation, and $b$ = measured breadth of standard line at the same Bragg angle). Similarly the curve obtained by Jones has also been used to correct the measured breadths of both the ferrite and martensite lines for the effect of the inhomogeneity of the X-radiation.

* Particle-size broadening is not appreciable when the average linear dimension of the crystals is greater than $10^{-4}$ cm.

Table II—*The Corrections for Instrumental Broadening* (*Specimen* PC*1*)

| Indices of Line | Measured Breadth ($b_o$, Ferrite, $B_o$, Martensite), mm. | Calculated Displacement of $K\alpha$ Doublet Peaks, $d$, mm. | $\frac{d}{b_o}$, Ferrite $\frac{d}{B_o}$, Martensite | $\frac{b}{b_o}$, Ferrite, $\frac{B_o}{B_o}$, Martensite* | Breadth Corrected for $K\alpha$ Doublet Effect ($b$, Ferrite; $B$, Martensite), mm. | $\frac{b}{B}$ | $\frac{\beta}{B}$† | Fully Corrected Breadth, $\beta$, mm. |
|---|---|---|---|---|---|---|---|---|
| Ferrite, line 2 | 0·408 | 0·107 | 0·262 | 0·925 | 0·377 | ... | ... | ... |
| Martensite, 101 + 011 | 0·870 | 0·102 | 0·117 | 0·985 | 0·857 | 0·440 | 0·690 | 0·591 |
| Martensite, 110 | 0·867 | 0·118 | 0·136 | 0·975 | 0·545 | 0·446 | 0·685 | 0·579 |
| Ferrite, line 4 | 0·428 | 0·178 | 0·416 | 0·810 | 0·347 | ... | ... | ... |
| Martensite, 002 | 1·607 | 0·166 | 0·103 | 0·985 | 1·580 | 0·220 | 0·900 | 1·420 |
| Martensite, 200 + 020 | 1·514 | 0·181 | 0·119 | 0·985 | 1·491 | 0·233 | 0·890 | 1·327 |
| Ferrite, line 6 | 0·560 | 0·285 | 0·509 | 0·745 | 0·417 | ... | ... | ... |
| Martensite, 112 | 1·900 | 0·265 | 0·139 | 0·980 | 1·862 | 0·224 | 0·895 | 1·666 |
| Martensite, 211 + 121 | 2·026 | 0·283 | 0·140 | 0·980 | 1·985 | 0·210 | 0·910 | 1·806 |
| Ferrite, line 8 | 0·909 | 0·639 | 0·703 | 0·695 | 0·632 | ... | ... | ... |
| Martensite, 202 + 022 | 4·005 | 0·516 | 0·129 | 0·985 | 3·945 | 0·160 | 0·950 | 3·748 |
| Martensite, 220 | 4·806 | 0·678 | 0·141 | 0·980 | 4·710 | 0·134 | 0·960 | 4·522 |

* From Jones' Fig. 5. † From Jones' Fig. 4.

The magnitudes of the various corrections are illustrated by the typical set of results (from specimen *PC*1) recorded in Table II.

### *Discussion of Results*

The results of the line-breadth measurements from each of the four specimens photographed are recorded in Table III, where the products $\beta \cos \theta$ and $\beta \cot \theta$ are also tabulated.

If the two lines constituting the martensite doublet *M*4 are for the moment neglected, it will be seen that for each specimen the product $\beta \cot \theta$ is much more nearly constant than $\beta \cos \theta$, the latter increasing fairly regularly from *M*2 to *M*8. Lines *M*2 afford particularly good evidence of the superiority of the cot $\theta$ function, since it is at these low angles that the distinction between cosine and cotangent is greatest.

On the basis of the evidence from the three doublets *M*2, *M*6, and *M*8 we should therefore conclude that the line broadening of martensite is more probably attributable to microstresses than to small particle size. The breadths of the two lines *M*4 appear anomalously high, however, the value of $\beta \cot \theta$ averaged over both lines for all specimens being 1·493 compared with 1·175 for all the other lines. This means that if a stress mechanism is the cause of the line broadening, the average strain in the direction [100]—which is very nearly perpendicular to the planes producing the 200 reflection—is greater than that in the directions [110] or [211].

For ferrite, the values for Young's modulus in these directions are,[10]

$$E_{[100]} = 18{\cdot}9 \times 10^6 \text{ lb./sq. in.}$$
$$E_{[110]} = 31{\cdot}3 \times 10^6 \text{ lb./sq. in.}$$
$$E_{[211]} = 31{\cdot}3 \times 10^6 \text{ lb./sq. in.}$$

It is reasonable to assume that approximately the same values will hold for martensite ; Young's modulus in the direction perpendicular to the planes which give rise to the *M*4 doublet is therefore only 0·6 times that in the directions perpendicular to the planes which give rise to the other lines. The breadth of the two lines constituting the *M*4 doublet is therefore accounted for by the fact that the strain in the direction [100] will be greater for a given stress than in the directions perpendicular to the planes giving rise to the other diffraction lines. The results from the pair of lines *M*4 reinforce the conclusion that the line broadening of martensite is due to a microstress mechanism rather than to small particle size. It should, however, be noted that the ratio of the Young's moduli is rather greater than is required to account for the observed line breadths, which may mean that the assumption that the average internal stress is independent of crystallographic direction is not strictly true.

A further respect in which the alternative

TABLE III—*Results of Line-Breadth Measurements*

| Indices of Line | Specimen *CA*1 | | | Specimen *CA*2 | | | Specimen *PB*2 | | | Specimen *PC*1 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Corrected Breadth | $\beta \cos \theta$ | $\beta \cot \theta$ | Corrected Breadth | $\beta \cos \theta$ | $\beta \cot \theta$ | Corrected Breadth | $\beta \cos \theta$ | $\beta \cot \theta$ | Corrected Breadth | $\beta \cos \theta$ | $\beta \cot \theta$ |
| 101<br>011 | 0·737 | 0·65 | 1·39 | 0·508 | 0·45 | 0·95 | 0·585 | 0·52 | 1·09 | 0·591 | 0·52 | 1·11 |
| 110 | 0·565 | 0·49 | 1·02 | 0·613 | 0·54 | 1·11 | 0·545 | 0·48 | 0·98 | 0·579 | 0·51 | 1·05 |
| 002 | 1·461 | 1·11 | 1·73 | 1·487 | 1·13 | 1·75 | 1·144 | 0·87 | 1·35 | 1·420 | 1·08 | 1·54 |
| 200<br>020 | 1·174 | 0·86 | 1·26 | 1·351 | 0·99 | 1·45 | 1·341 | 0·98 | 1·44 | 1·327 | 0·97 | 1·42 |
| 112 | 1·483 | 0·88 | 1·10 | 1·530 | 0·86 | 1·04 | 1·630 | 0·97 | 1·20 | 1·666 | 0·99 | 1·22 |
| 211<br>121 | 1·583 | 0·89 | 1·07 | 1·940 | 1·15 | 1·43 | 1·679 | 0·94 | 1·14 | 1·806 | 1·02 | 1·23 |
| 202<br>022 | 3·355 | 1·24 | 1·33 | 3·368 | 1·18 | 1·26 | 2·547 | 0·89 | 0·96 | 3·748 | 1·32 | 1·41 |
| 220 | 4·075 | 1·12 | 1·17 | 4·451 | 1·22 | 1·27 | 4·762 | 1·31 | 1·36 | 4·522 | 1·25 | 1·31 |

theories of line broadening may be compared is in the magnitude of the effect and consequently of the particle size or microstresses required to account for it.

From Table III a mean value of 0·918 for $\beta \cos \theta$ is obtained by averaging over all lines and all specimens. A value for $l$, the average crystallite dimension, can then be found from the Scherrer formula,

$$l = \frac{K\lambda}{\beta \cos \theta}$$

where $K$ is a constant approximately equal to unity and $\lambda$ is the X-ray wavelength. This value is found to be of the order $2 \times 10^{-7}$ cm., or approximately seven interatomic distances. It is difficult to conceive of the existence of a stable substructure on such an extremely fine scale.

If, on the other hand, we assume that microstresses are the cause of line broadening, a value for the "average stress" in the structure can be obtained from the equation,

$$f = \frac{E\beta \cot \theta}{4R}$$

where $f$ is the average stress; $E$, the average value of Young's modulus, is taken to be $30 \times 10^6$ lb./sq. in.; $\beta \cot \theta$ is averaged as 1·25 from Table III; and $R$ is the radius of the camera in cm.[11] This yields a value of 93 tons/sq. in. for the average stress, a figure which lies between the yield point and the ultimate tensile stress of the material. This result can be regarded as a reasonable one and in general agreement with the view of the transformation from austenite to martensite which the authors have developed elsewhere,[12] an essential feature of which is that the strains associated with the transformation are finite, so that the stresses between independently formed martensite plates may be expected to exceed the yield point.

The general conclusion from this work is therefore that, while the possibility of line broadening by small particles has not been entirely disproved, the balanced local internal stresses which the martensitic structure is known to contain are in themselves adequate to account for the observed line breadths, and must in any case be responsible for the major part of the broadening.

## Acknowledgments

This work forms part of a research being undertaken for the FM. 1 Committee of the British Welding Research Association under the direction of Professor D. Hanson, D.Sc. The authors wish to thank Professor Hanson for his advice and active encouragement, and the Association for permission to publish this paper.

Their thanks are due to Professor Sir Lawrence Bragg, F.R.S., for permission to use the facilities of the Cavendish Laboratory, Cambridge, and particularly to Dr. H. Lipson and Miss A. M. B. Parker for much valuable advice and discussion.

They would like also to thank Mr. H. F. Tremlett who arranged the supply of the commercial high-carbon steel, and Mr. J. W. Gailer who undertook the analysis of the specimens.

## References

1. A. Westgren : *Journal of the Iron and Steel Institute*, 1921, vol. 103, p. 303.
2. A. J. Bradley and W. L. Bragg : *Journal of the Iron and Steel Institute*, 1940, vol. 141, p. 70P.
3. G. L. Clark : "Applied X-rays," p. 498. New York, 1940 : McGraw-Hill.
4. A. Taylor : "An Introduction to X-ray Metallography," p. 203. London, 1945 : Chapman and Hall.
5. F. F. Lucas : *Transactions of the American Institute of Mining and Metallurgical Engineers*, 1931, vol. 95, p. 11.
6. U. Dehlinger and A. Kochendorfer : *Zeitschrift für Kristallographie*, 1939, vol. 101, p. 134.
7. W. A. Wood : *Nature*, 1943, vol. 151, p. 585.
8. H. Lipson and A. M. B. Parker : *Journal of the Iron and Steel Institute*, 1944, vol. 149, p. 123P.
9. F. W. Jones : *Proceedings of the Royal Society*, 1938, *Series* A, vol. 166, p. 16.
10. "Metals Handbook," 1939 Edition, p. 442.
11. H. D. Megaw and A. R. Stokes : *Journal of the Institute of Metals*, 1945, vol. 71, p. 279.
12. M. A. Jaswon and J. A. Wheeler : "Atomic Movements in the Transformation from Austenite to Martensite." Draft Copy, 1946.

# The Mechanism of Carbon Removal in the Open-Hearth Furnace*

*By the late A. H. Jay, M.Sc., Ph.D., F.Inst.P., F.I.M.*†

SYNOPSIS

*An account is given of the development of a suggested mechanism for the carbon-removal action from liquid steel in open-hearth furnaces.*

*A critical examination of a typical acid open-hearth cast shows that the rates of carbon removal at two definite periods* (i.e., *at the end of the ore boil and during the limestone boil, when the respective carbon contents are widely dissimilar*) *are closely related only to the degrees of oxidation at these stages* (*as judged by the respective silicon and manganese contents*) *rather than to the product of the carbon and oxygen contents. This conclusion is supported by many previous observations of steelmaking data. On this basis, a mechanism is evolved which postulates the following chain of reactions :* (1) *C (soluble) + O (soluble) → CO (insoluble molecular gas bubble) ;* (2) $CO + O \rightarrow CO_2$ ; (3) $CO_2 + C \rightarrow 2CO$. *A two-stage reaction* (*equations* (2) *and* (3)) *thus proceeds with subsequent growth of the bubble. In view of the very low ratio of oxygen to carbon in the medium-high carbon ranges, it is considered that reaction* (2) *is the governing factor in determining the ultimate speed of carbon removal.*

*The hypothesis is also substantiated by calculations of the relative concentrations of oxygen and iron atoms on the surface of the primary molecular CO gas bubble. These show that the CO gas bubble can accommodate 3300 iron atoms. If, therefore, at least one oxygen atom is present on the bubble surface, as might well be necessary in order to allow the reaction to proceed, it can readily be shown that the overall oxygen content of the liquid bath would be 0·009%. This value is in remarkable agreement with experimental data—particularly American—which indicate that for steady carbon removal a minimum excess oxygen content,* e.g., *0·009%* (i.e., *excess oxygen over the equilibrium value*) *is required in the medium-high carbon ranges.*

## I—INTRODUCTION

THE subject of the mechanism of removal by oxidation of carbon from the bath of metal in an open-hearth furnace has received much attention in the past. For many years the reaction has been regarded as a simple one, and it is often expressed by the equation FeO + C = Fe + CO, where FeO and C are regarded as the concentrations of active oxide and carbon in liquid steel. Early work by Herty was taken as proof of the correctness of this expression ; he also stated that the rate of carbon removal was dependent upon the product of the carbon and oxygen concentrations and would be expressed by the equation :

$$\frac{dC}{dt} = K_1 \times [C] \times [O] - K_2$$

where [C] and [O] are the carbon and oxygen concentrations as determined by chemical analysis, and $K_1$ is a velocity constant. The value $K_2$ is a constant involving the equilibrium product of carbon and oxygen in liquid steel.

These ideas have been accepted by many later workers and used in the determination of oxygen in liquid steel. The writer met this problem during a study of the chemical compositions of metal and slag samples taken from acid open-hearth furnaces at the works of Messrs. Steel, Peech and Tozer, Ltd.

* Received 22nd March, 1947.

† The United Steel Companies, Ltd., Stocksbridge, near Sheffield. Dr. Jay died on 22nd February, 1947.

Following a certain line of reasoning, which will be detailed later, the conclusion was reached that the rate of carbon removal was proportional only to the " degree of oxidation " of the metal. This contradiction of the theory stated above was at first a disturbing fact, but finally it led to a new approach to the study of the carbon–oxygen reaction in the bath of liquid steel. This new theory has been checked by use of atomic and molecular constants and a remarkable result has been reached, namely, that for steady carbon removal, liquid steel in an open-hearth furnace should contain not less than 0·04% of FeO in excess of the equilibrium FeO percentage content. This value is also the minimum excess FeO content in liquid steel in basic open-hearth practice, as seen from recent American publications[1,2] (see Fig. 3).

The reactions visualized in this can be stated as follows : One soluble carbon atom unites with one soluble oxygen atom to form one gas molecule of carbon monoxide, thus :

$$C + O \longrightarrow CO \text{ (gas)}.$$

The following reactions take place in the gas phase, or perhaps more strictly at the gas–metal interface within the mass of metal. A molecular bubble of carbon monoxide gas is oxidized by one oxygen atom to form one molecule of carbon dioxide gas, thus :

$$CO + O \longrightarrow CO_2.$$

This carbon dioxide reacts with one atom of carbon to form a larger bubble of carbon monoxide:

$$CO_2 + C \longrightarrow 2CO.$$

The process once started proceeds with the growth of gas bubbles, *viz.* :

$$2CO + O \longrightarrow CO + CO_2$$
$$CO + CO_2 + C \longrightarrow 3CO.$$

## II—Slag and Metal Analyses and Reactions

Details of the refining period in the acid steel-making process for a cast of forging-quality steel, in terms of chemical composition, are given in Table I and Fig. 1.

### (a) *Discussion of Changes in Metal Composition*

During the ore-boiling period, a rapid fall takes place in the silicon and manganese contents down to low mean values, *viz.*, 0·035% for silicon and 0·13% for manganese. These low values are maintained for ¾ hr., during which time the carbon shows a steady rate of removal. During the limestone-boiling period, the silicon and manganese contents rise to maximum values of 0·21% for silicon and 0·215% for manganese. These values are maintained for some time, *viz.*, 45 min., so that a measure of the rate of carbon drop may be obtained under conditions of uniform manganese and silicon contents.

### (b) *Discussion of Slag Analyses*

It will be sufficient to indicate the changes in slag analysis which are relevant to the present problem. The average slag analyses in the two periods of steady manganese and silicon contents of the metal are as follows :

| Time | $SiO_2$, % | Fe, % | CaO, % | MnO, % |
|---|---|---|---|---|
| End of ore boil ... | 59·2 | 12·1 | 5·8 | 17·1 |
| End of limestone boil ... | 61·6 | 7·7 | 11·7 | 14·1 |

### (c) *Slag–Metal Reactions*

The reactions between silicon, manganese, oxygen, silica, and manganese oxides are assumed to be as follows :

$$Si + 2O = SiO_2$$
$$Mn + O = MnO$$

It is appreciated that the concentration of silicon and manganese in the liquid steel will depend not only on the degree of oxidation of the metal but on the concentration of $SiO_2$ and MnO, respectively, in the overlying slag. Thus, in considering metal compositions in relation to degree of oxidation for the two periods, the effect of slag composition must also be borne in mind.

## III—Degree of Oxidation of the Metal and Rate of Carbon Removal

In spite of the fact that tests were not made to determine directly the oxygen content of the

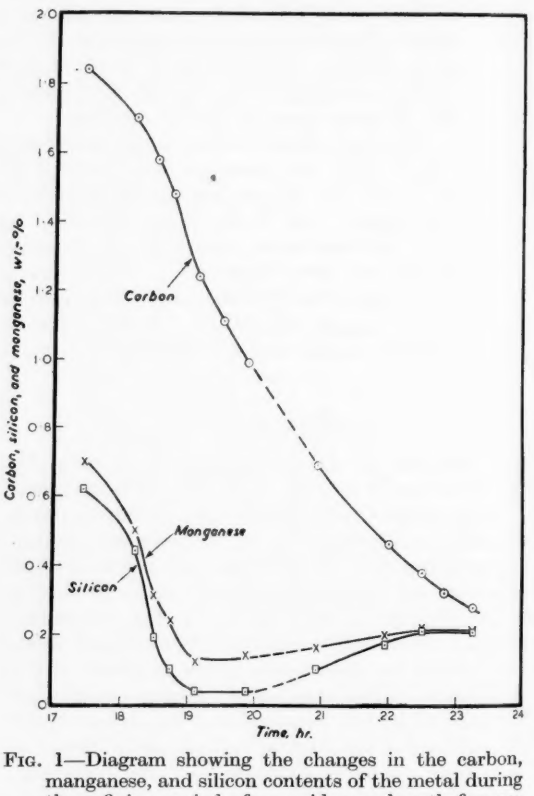



Fig. 1—Diagram showing the changes in the carbon, manganese, and silicon contents of the metal during the refining period of an acid open-hearth furnace charge

TABLE I—*Details of Metal and Slag Compositions in the Refining Period of an Acid Open-Hearth Heat*

| Time | | Additions | Metal Composition | | | Slag Composition | | | |
|---|---|---|---|---|---|---|---|---|---|
| Hr. | Min. | | C, % | Si, % | Mn, % | $SiO_2$, % | Fe, % | CaO, % | MnO, % |
| 17 | 25 | ... | 1·84 | 0·62 | 0·70 | ... | ... | ... | ... |
| 12 | 55 | Ore | | | | | | | |
| 18 | 10 | ... | 1·70 | 0·44 | 0·50 | ... | ... | ... | ... |
| 18 | 15 | Ore | | | | | | | |
| 18 | 30 | ... | 1·58 | 0·19 | 0·31 | ... | ... | ... | ... |
| 18 | 35 | Ore | | | | | | | |
| 18 | 45 | ... | 1·48 | 0·10 | 0·24 | ... | ... | ... | ... |
| 18 | 50 | Ore | | | | | | | |
| 19 | 08 | ... | 1·24 | 0·034 | 0·12 | 58·8 | 12·0 | 5·9 | 17·6 |
| 19 | 10 | Ore | | | | | | | |
| 19 | 30 | ... | 1·11 | ... | ... | 59·4 | 11·4 | 5·9 | 17·0 |
| 19 | 35 | Ore | | | | | | | |
| 19 | 52 | ... | 0·99 | 0·034 | 0·14 | 59·5 | 13·0 | 5·7 | 16·7 |
| 19 | 55 | Limestone | | | | | | | |
| 20 | 55 | ... | 0·69 | 0·10 | 0·16 | ... | ... | ... | ... |
| 22 | 00 | ... | 0·46 | 0·17 | 0·20 | ... | ... | ... | ... |
| 22 | 30 | ... | 0·38 | 0·21 | 0·22 | 61·1 | 7·8 | 11·7 | 14·3 |
| 22 | 50 | ... | 0·32 | ... | ... | ... | ... | ... | ... |
| 23 | 15 | ... | 0·28 | 0·21 | 0·21 | 62·1 | 7·7 | 11·7 | 14·0 |

liquid metal, it appeared to the writer that the silicon and manganese contents could be regarded as criteria of the degree of oxidation, at least when these elements are maintained at steady values for reasonable periods of time. Thus, apart from any consideration of the absolute value of the oxygen content, it would appear that the ratio of the silicon and of the manganese contents for the two periods, *i.e.*, the end of the ore boil and the end of the limestone boil, can be used to give a measure of the relative degrees of oxidation of the metal at these periods.

The reaction constants for the two metal–slag reactions previously given are :

$$K_{Si} = \frac{[Si][O]^2}{(SiO_2)} \quad \text{and} \quad K_{Mn} = \frac{[Mn][O]}{(MnO)},$$

where [Si], [Mn], and [O] refer to metal concentrations, while ($SiO_2$) and (MnO) refer to slag concentrations. On the assumption that the temperatures at the two periods are not widely different and hence no temperature corrections are required, the values of $K_{Si}$ for the two periods, and also those for $K_{Mn}$, may be equated :

$$\frac{[Mn]\,a\,[O]\,a}{(MnO)\,a} = \frac{[Mn]\,b\,[O]\,b}{(MnO)\,b}$$

and

$$\frac{[Si]\,a\,[O]^2\,a}{(SiO_2)a} = \frac{[Si]\,b\,[O]^2\,b}{(SiO_2)\,b}.$$

The suffixes *a* and *b* refer to the two periods under examination. Therefore, the ratio of the degrees of oxidation of the metal at these periods is given by :

$$\frac{[O]\,a}{[O]\,b} = \sqrt{\frac{[Si]\,b}{[Si]\,a} \times \frac{(SiO_2)\,a}{(SiO_2)\,b}} \quad \text{from the silicon reaction,}$$

and

$$\frac{[O]\,a}{[O]\,b} = \frac{[Mn]\,b}{[Mn]\,a} \times \frac{(MnO)\,a}{(MnO)\,b} \quad \text{from the manganese reaction.}$$

On this basis, the ratio of the degrees of oxidation for the typical cast shown in Fig. 1 at the two periods is obtained as follows :

(*a*) From the silicon reaction

$$\frac{[O]\,a}{[O]\,b} = \sqrt{\frac{0{\cdot}21}{0{\cdot}035} \times \frac{59{\cdot}2}{61{\cdot}6}}$$
$$= \sqrt{5{\cdot}75}$$
$$= 2{\cdot}4.$$

(*b*) From the manganese reaction

$$\frac{[O]\,a}{[O]\,b} = \frac{0{\cdot}215}{0{\cdot}13} \times \frac{17{\cdot}1}{14{\cdot}1}$$
$$= 2{\cdot}0.$$

These facts are summarized in Table II.

An examination of the above data shows that the ratio of the rates of carbon removal approximates very closely to the ratio of the degrees of oxidation, as assessed by the changes in silicon and manganese contents of the metal for the two periods when silicon and manganese are maintained at steady values. This is a surprising result, considering that the carbon contents at these periods are so different, namely, 1·1% and 0·33%, and that the accepted theory requires the rate of carbon removal to be proportional to the product of the oxygen and carbon contents.

Accepting the accuracy of the chemical data and the correctness of the assumption that the silicon and manganese contents act as criteria of the degree of oxidation, the conclusion is that the rate of carbon removal is controlled by the oxygen

TABLE II—*Summary of Degree of Oxidation of the Metal and Rate of Carbon Removal*

| | Metal Analyses | | Ratio $M_2/M_1$ | | |
|---|---|---|---|---|---|
| | Stage *a* (End of Ore Boil) ($M_1$) | Stage *b* (End of Limestone Boil) ($M_2$) | As Read | Corrected for Slag Analyses | Ratio of Degree of Oxidation, $\frac{\text{Stage } (a)}{\text{Stage } (b)}$ |
| Silicon ... ... | 0·035% | 0·21% | 6·0 | 5·75 | $\sqrt{5·75} = 2·4$ |
| Manganese ... ... | 0·13% | 0·215% | 1·65 | 2·0 | $2·0$ |
| | | | | | Average 2·2 |
| Rate of carbon removal, %/hr. | 0·34 (1·1% C) | 0·135 (0·33% C) | Ratio of rates of carbon removal = 2·5 | | |

content of the metal rather than by the product of the oxygen and carbon contents.

It is worthy of note that while workers in this country[3] have held the view that the carbon/oxygen reaction is of the form FeO + C = Fe + CO, others in the U.S.A.[1] have for some time shown concern and even speculation regarding the lack of agreement between experimental facts and the accepted theory.

## IV—Suggested Mechanism for the Carbon–Oxygen Reaction

For simplicity, let us consider a steel containing only iron, carbon, and oxygen. This steel in the liquid condition is considered to be a solution of carbon and oxygen atoms in liquid iron, *viz.*, an intimate mixture of iron, carbon, and oxygen atoms. The limits of solubility of carbon and oxygen in liquid iron may be represented as in Fig. 2, by the line *AB*. The shaded portion is a single-phase region (liquid) where carbon and oxygen atoms are soluble in molten iron.

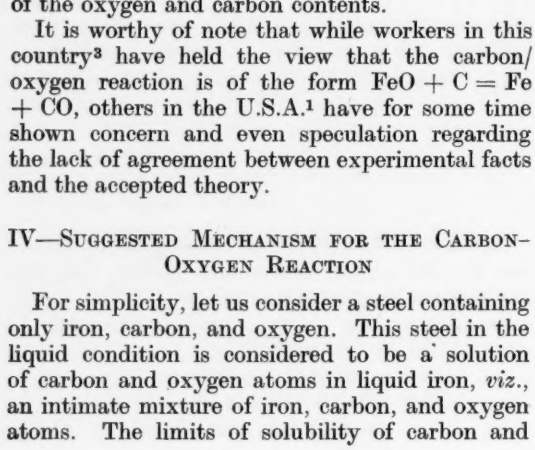



FIG. 2—Diagram illustrating the solubility of carbon and oxygen in liquid iron

The two-phase region consists of liquid iron and a gas phase. The line *AB* represents a condition where :

C (soluble) + O (soluble) ⟶ CO gas (insoluble)...(1)

(In this equation CO is used, firstly because the ratio of oxygen to carbon is usually very small (medium–high carbon steels) and only approaches equality for very low-carbon steels (less than 0·10% of carbon), and secondly because the formation of carbon monoxide involves the collision of only two atoms.)

The above expression does not mean that carbon monoxide is soluble in liquid iron, neither does it infer any escape of gas.

The expression is intended to indicate a condition where tiny bubbles of gas corresponding to and containing one molecule of carbon monoxide are continually being created and annihilated throughout the system. The creation of gas molecules of carbon monoxide could, of course, take place throughout the two-phase region shown in Fig. 2, and it is important now to consider how such gas molecules escape from the liquid metal.

In view of the extremely small size of the " sphere of influence " of a single gas molecule, it is not considered possible to account for the removal of carbon from liquid steel by gravitational forces. Growth of " molecular gas bubbles " by collision is not considered to be a prime factor in gas escape and carbon elimination.

The steel may be considered as a mixture of liquid (containing iron, carbon, and oxygen atoms) and gas bubbles each of one molecule of carbon monoxide. Subsequent reactions are thus between carbon monoxide gas, and carbon and oxygen atoms. The following reactions are suggested for the growth and final escape of large gas bubbles :

$$CO\ (gas) + O \longrightarrow CO_2\ (gas) \quad \ldots\ldots(2)$$
$$CO_2\ (gas) + C \longrightarrow 2CO\ (gas) \quad \ldots\ldots(3)$$

The reactions take place in the gas phase inside the liquid steel, and the continued growth of each primary gas bubble is indicated thus:

$$2CO + O \longrightarrow CO_2 + CO$$
$$CO_2 + CO + C \longrightarrow 3CO$$

The elimination of carbon is thus a two-stage reaction, the speeds of the two component reactions being dependent respectively on the degree of oxidation and carbon content. As the ratio of oxygen to carbon is small (except in the very low carbon ranges), the degree of oxidation is considered to be the governing factor in determining the ultimate rate of carbon removal.

## V—Test of the New Theory

A quantitative test of this new hypothesis was made by a calculation of the oxygen content, in excess of the equilibrium content, required for the reaction, *viz.*, $CO + O = CO_2$, to proceed at a steady rate.

The volume corresponding to 1 gramme-molecule of carbon monoxide is 22·4 litres at N.T.P. This volume is increased by the ratio (1600 + 273)/273 for an assumed furnace temperature of 1600° C. The volume is decreased by some ratio dependent upon the actual pressure inside the liquid steel. In the case of a slag 6 in. thick with a specific gravity of 3, the increase in pressure at a position corresponding to the slag–metal interface is equal to 0·05 atm. At a position in the metal 3 in. below the slag–metal interface, the further increase in pressure is of the order of 0·06 atm. The total decrease in volume owing to increased pressure will therefore be approximately 10% for metal near the slag. Thus the volume of a molecular gas bubble of carbon monoxide is equal to:

$$22{\cdot}4 \times 10^3 \times \frac{1873}{273} \times \frac{1}{1{\cdot}10} \times \frac{1}{N} \text{ c.c.},$$

where $N = 6{\cdot}02 \times 10^{23}$, the number of molecules per gramme-molecule.

This volume is equal to $232{,}000 \times 10^{-24}$ c.c., and may be regarded as the sphere of influence consequent upon the thermal movement of one gas molecule. The radius of this molecular bubble is $38 \times 10^{-8}$ cm., *i.e.*, 38Å., where $10^{-8}$ cm. = Å.; its surface area is 18,200 Å.$^2$ The number of iron atoms in a unit layer over the surface of this sphere is clearly the total area of the sphere divided by the effective surface area of the iron atom. This latter quantity has been calculated as follows:

Volume per iron atom at room temperature
$= \frac{1}{2}(2{\cdot}86\text{Å.})^3$,

for a specific gravity of 7·86. The volume per atom at 1600° C. is equal to $\frac{1}{2}(2{\cdot}86\text{Å.})^3 \times 7{\cdot}86/7{\cdot}15$, where 7·15 is the specific gravity at 1600° C. The effective surface area per atom at 1600° C. is thus equal to $[\frac{1}{2}(2{\cdot}86\text{Å.})^3 \times 1{\cdot}10]^{\frac{2}{3}} = 5{\cdot}5\text{Å}^2$. Comparing this value with 18,200Å$^2$ gives 3300 iron atoms in the unit atomic layer on the surface of the primary molecular gas bubble. Now, for the reaction $CO + O = CO_2$ to proceed, there must be at least one oxygen atom in the unit atomic layer, *i.e.*, one oxygen atom per 3300 iron atoms. This is equal to a concentration of oxygen in the metal of 0·009%, or 0·04% of ferrous oxide. Thus the conclusion is that for a steady rate of carbon removal the minimum excess oxygen content above the equilibrium value is equal to 0·009% (or 0·04% of FeO). The rate of carbon removal will naturally be increased for higher degrees of oxidation.

The oxidation of carbon monoxide allows the subsequent reaction $CO_2 + C = 2CO$ to proceed. For medium–high carbon steels this reaction will proceed to the right, in view of the relative abundance of carbon to oxygen atoms.

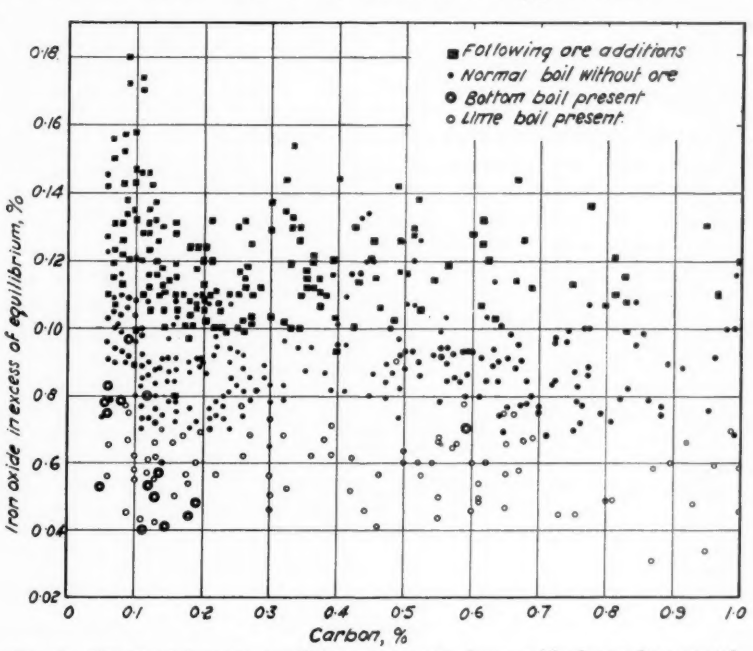



FIG. 3—Effect of furnace conditions on excess iron oxide for molten metal of various carbon contents (Larsen)

It is important to note that the reaction $CO + O = CO_2$ *can* proceed with excess oxygen contents less than the 0·009% calculated above, on the assumption that a portion of the molecular bubbles will form where the necessary oxygen content (0·009%) is present. The process is then governed by statistical probability, and such a reaction will be very slow. In fact, it appears that in the open-hearth furnace, where there is a high potential oxygen supply (the overlaying slag) and high rates of carbon removal obtain, the minimum excess oxygen content of 0·009% is necessary. This conclusion is a remarkable one, since the carbon–oxygen data presented by Larsen for the basic open-hearth process indicates that there is a minimum of 0·04% FeO (0·009% of oxygen) excess over equilibrium values (*see* Fig. 3).

## VI—Summary and Conclusions

(1) Consideration of experimental results from acid open-hearth casts did not support the theory that the rate of carbon removal was dependent upon the product of carbon and oxygen contents of the metal for carbon ranges of up to 1%.

The present data suggest that for medium–high carbon ranges the rate of carbon removal is dependent on the degree of oxidation of the metal.

(2) A new approach has been made to the mechanism of carbon removal. It is considered that the reactions take place within a gas phase in the molten steel bath.

(3) The reactions are considered to be as follows :

$$C\ (\text{soluble}) + O\ (\text{soluble}) \longrightarrow CO\ (\text{insoluble gas}) \quad \ldots(1)$$
$$CO + O \longrightarrow CO_2 \quad \ldots(2)$$
$$CO_2 + C \longrightarrow 2CO \quad \ldots(3)$$

It is interesting to note that for very low carbon contents (say, less than 0·10%), where the oxygen and carbon contents become more nearly equal, the escaping gas should not be pure carbon monoxide but a mixture of CO and $CO_2$.

(4) The above reactions offer an explanation why, according to recent American work, the rate of carbon removal is not dependent upon the product of the carbon and oxygen contents but is dependent upon the degree of oxidation.

(5) The reaction C + O = CO offers an explanation of why carbon elimination does not always take place even when the necessary oxygen content is present, in the sense that the formation of molecular bubbles may be retarded. This would be regarded as supersaturation, a not infrequent phenomenon met with in the study of phase assemblages.

Experimentally it has been observed that a bath of liquid steel can hold many times the equilibrium amount of oxygen until the steel is disturbed, after which rapid reaction follows.

(6) The calculated minimum excess of oxygen content above the equilibrium value for steady removal of carbon is 0·009% (*i.e.*, 0·04% of FeO), a figure in remarkable agreement with the minimum excess value for ferrous oxide of the many results obtained in basic open-hearth practice and presented by Larsen.

## VII—Acknowledgment

The author thanks Mr. F. H. Saniter, Director of Research, The United Steel Companies, Ltd., for permission to publish this paper.

## References

1. B. M. Larsen : *Transactions of the American Institute of Mining and Metallurgical Engineers*, 1941, vol. 145, pp. 67–78.
2. " Basic Open-Hearth Steelmaking." New York, 1944 : The American Institute of Mining and Metallurgical Engineers.
3. A. McCance : *The Iron and Steel Institute*, 1938, *Special Report No.* 22, pp. 331–371.

# Some Aspects of the Refining of High-Phosphorus Iron*

*By W. L. Kerlie, B.Sc.*†


## Synopsis

*A comparison is made of the phosphorus and carbon equilibria and the factors affecting the rate of carbon removal in the refining of iron are explained on a thermodynamical basis. On the basis of the general equations developed, two examples of the refining of high-phosphorus iron are quoted and certain conclusions are reached from an examination of the results.*

*The factors which determine the oxide requirements and processing time are considered and some notes on the more practical aspects of refining are given.*


## Introduction

The rising costs of fuel and hematite iron and the economic advantages attending the use of greater quantities of home ore are leading to a demand for a process of refining high-phosphorus iron whereby a metal is produced which is suitable for subsequent use in the open-hearth furnace. The economics of such a process will be adversely affected if the slag produced has a low $P_2O_5$ content or is otherwise unsuitable as a fertiliser. The idea of refining high-phosphorus iron to a composition suitable for fixed furnaces is particularly attractive and, in the following notes, this idea has been kept in mind.

## Theoretical Considerations

In a process of iron refining where mechanical agitation of the metal and slag is absent or impracticable the carbon reaction must be utilized to provide the necessary mixing of slag and metal for the various reactions to occur at speeds consistent with practical demands. If it is considered that the rate of oxidation of the carbon can be controlled within certain required limits, such as will permit of adequate agitation of the bath, the factors influencing the course of the reactions can be examined first of all on a theoretical basis.

### *The Phosphorus Reaction*

If the phosphorus reaction is assumed to be

$$2P + 5FeO + 4CaO = 4CaO \cdot P_2O_5 + 5Fe,$$

and adopting Schenck's[1] method of treatment, which according to Zea[2] is the most accurate method available, the values of $K_P$, the equilibrium constant of the phosphorus reaction, and $\log K_P$ may be represented by:

$$K_P = \frac{(\Sigma P_2O_5)}{[P](FeO)^5(CaO)^4} \cdot 10^{-0{\cdot}06\,(\Sigma P_2O_5)} \quad \text{.....(1)}$$

and

$$\log K_P = \frac{51{,}800}{T} - 35{\cdot}05 \quad \text{.....(2)}$$

where $(\Sigma P_2O_5)$ represents the total concentration in the slag, (FeO) and (CaO) represent "free" or active concentrations in the slag, and [P] is the phosphorus content of the metal during equilibrium.

The "driving force" or affinity of the reaction may be represented by the available-energy change $(-\Delta G_P)$‡ and may be evaluated diagrammatically in a manner similar to that given by Ellingham,[3] taking $X_P$ as the activity quotient or the result when the concentrations under active conditions are used. Thus

$$-\Delta G_P = RT \ln K_P - RT \ln X_P \text{ cal.} \quad \text{.....(3)}$$

$$= 4{\cdot}573T\,(\log K_P - \log X_P). \quad \text{.....(4)}$$

At equilibrium $X_P$ will have the same value as $K_P$ and therefore $-\Delta G_P$ will be zero.

If the values of $K_P$ and $\log K_P$ in equations (1)

* Received 21st March, 1947.

† Messrs. Stewarts and Lloyds, Ltd., Corby.

‡ This is referred to by some authors as the "free" energy, and by American authors the symbol $-\Delta F$ is used.

and (2) are substituted in equation (4), the expression for the available-energy change becomes:

$$-\Delta G_P = 4{\cdot}573T\left(\frac{51{,}800}{T} - 35{\cdot}05 - \log\frac{d}{a\,b^5\,c^4} + 0{\cdot}06d\right) \quad \text{.....(5)}$$

where, at any given instant,

$a$ = phosphorus in the metal, %,
$b$ = free FeO in the slag, %,
$c$ = free CaO in the slag, %,
$d$ = total $P_2O_5$ in the slag, %, and
$T$ = absolute temperature.

The values of $b$, $c$, and $d$ vary with the temperature and with the contents of Fe, MnO, and $SiO_2$ in the slag, and may be found from charts III to V of Schenck[1] after calculating (CaO)′, the concentration of lime other than that required for the formation of 4 CaO . $P_2O_5$, *viz.*,

$$(CaO)' = (\Sigma CaO) - 1{\cdot}57\,(\Sigma P_2O_5).$$

The dephosphorizing power of a slag may be evaluated using equation (5), but if direct comparison is to be made with the carbon reaction

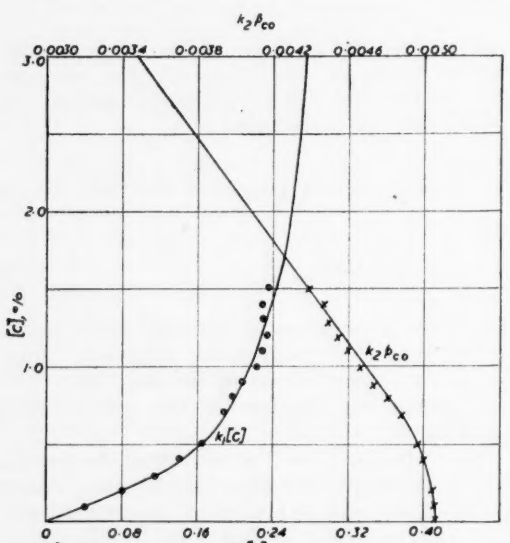



FIG. 1—Variation in $k_1$[C] and $k_2p_{CO}$ with [C] (based on values of $k_1$ and $k_2$ given by Schenck)

in order to determine which reaction will take precedence the same basis must be used. The phosphorus reaction described above is based on 5 mols of reacting (FeO) and, if the supply of FeO in a given time is limited, the affinity of the reaction per mol (FeO) may be taken, for purposes of comparison, as

$$A_P = -\frac{\Delta G_P}{5} = 0{\cdot}9146T\left(\frac{51{,}800}{T} - 35{\cdot}05 - \log\frac{d}{a.b^5.c^4} + 0{\cdot}06d\right) \text{cal.....(6)}$$

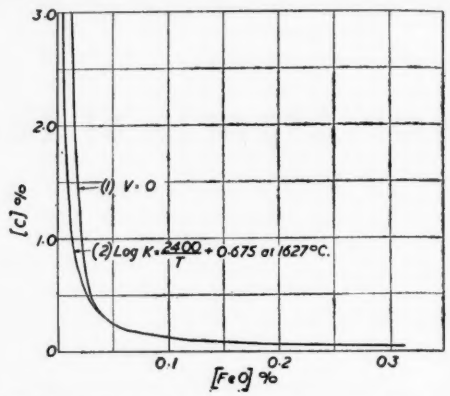



FIG. 2—Comparison of [C] and [FeO] equilibrium curves based on data by (1) Schenck and (2) Chipman and Samarin

### *The Carbon Reaction*

In the reaction

$$[C] + [FeO] = Fe + CO$$

the value of [FeO] may be found by making use of the partition coefficient

$$L_{FeO} = 0{\cdot}588 \times 10^{-4}t - 0{\cdot}0793 \quad \text{.....(7)}$$

That is,

$$[FeO] = (FeO)\,(0{\cdot}588 \times 10^{-4}t - 0{\cdot}0793),$$

where $t$ is the temperature in °C.

The equilibrium constant of the reaction is given by

$$K_C = \frac{p_{CO}}{[C]\,[FeO]} \quad \text{.....(8)}$$

and from the work of Chipman and Samarin[1]

$$\log K_C = \frac{2400}{T} + 0{\cdot}675 \quad \text{.....(9)}$$

$$RT \ln K_C = 10{,}980 + 3{\cdot}09\,T \quad \text{.....(10)}$$

The experimental data, from which equation (9) is derived, only cover the range of carbon content up to 0·2%. In order to test at the higher carbon contents encountered in iron-refining practice a comparison was made with the results based on the velocity constants given by Schenck. The rate of carbon removal is given by:

$$v = k_1\,[C]\,[FeO] - k_2p_{CO} \text{ \% per min.} \quad \text{.....(11)}$$

from which the FeO content of the metal becomes

$$[FeO] = \frac{v + k_2\,p_{CO}}{k_1\,[C]} \quad \text{.....(12)}$$

Schenck's values for $k_1$[C] and $k_2p_{CO}$ cover the range up to 1·5% carbon, and Fig. 1 has been drawn with the values extended up to 3·0% of carbon. Using these values of $k_1$[C] and $k_2p_{CO}$ the [FeO] contents at different carbon contents were calculated for equilibrium conditions ($v = 0$) from equation (12) and the equilibrium curve based on Schenck's results was obtained, as

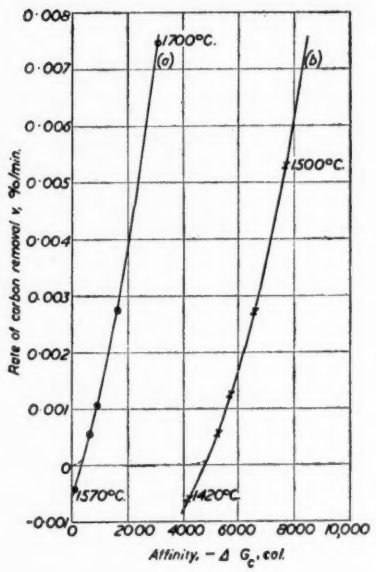



FIG. 3—Variation in affinity with rate of carbon removal for (*a*) an open-hearth heat and (*b*) iron refining

shown in Fig. 2. Using equations (8) and (9) the equilibrium curve based on the results of Chipman and Samarin was evolved for a temperature of 1627° C. and $p_{CO} = 1$ atm. As shown in Fig. 2 perfect agreement up to 0·3% of carbon and good agreement up to 3·0% of carbon were obtained.

Using equations (9) and (10) the available energy of the carbon reaction may now be written in the form

$$-\Delta G_C = RT \ln K_C - RT \ln X_C$$
$$= 10{,}980 + 3{\cdot}09T - 4{\cdot}573\,T \log \frac{1{\cdot}1}{e \cdot f} \text{ cal.} \quad ...(13)$$

where $e$ is the carbon content and $f$ is the FeO concentration in the metal.

Equation 13 represents the affinity in cal. per mol [FeO] dissolved in the metal. For comparison with the phosphorus reaction, the affinity $A_C$ per mol of free (FeO) in the slag is required and can be calculated from equations (7) and (13), thus :

$$A_C = -\Delta G_C . L_{FeO}$$
$$= -\Delta G_C (0{\cdot}588 \times 10^{-4}t - 0{\cdot}0793) \text{ cal.}$$
$$= -\Delta G_C (0{\cdot}588 \times 10^{-4}T - 0{\cdot}09535) \text{ cal.} \quad ...(14)$$

It should be noted that the affinity is not necessarily a measure of the velocity of a reaction. In the case of the high-temperature metallurgical reactions involved in iron refining and steelmaking, where fluid metal and slag are present, it can be shown that the affinity is a measure of the reaction velocity for a given metal and slag composition. For example, in Fig. 3 the variation in the rate of carbon removal with affinity is given for the two refining conditions :

(*a*) An open-hearth heat with 0·2% of carbon in the metal and a slag containing 10% of Fe, 47% of CaO, 6% of $P_2O_5$, 12% of $SiO_2$, and 10% of MnO.

(*b*) The refining of iron with 2·8% of carbon and a slag containing 6·84% of Fe, 45·5% of CaO, 12·3% of $P_2O_5$, 13·9% of $SiO_2$, and 3·6% of MnO.

In each case an approximately rectilinear relationship exists between the rate of carbon removal ($v$%/min.) and the affinity ($-\Delta G_C$ cal.). In case (*b*) the temperature range is, of course, lower, but the affinity for a given rate of carbon removal is much greater.

Negative values of $v$ will not obtain in actual practice. As $v$ tends towards zero $p_{CO}$ will decrease, during which time $-\Delta G_C$ will also tend towards zero. The dotted lines have consequently been drawn in to represent, more accurately, working conditions at or near equilibrium.

## COMPARISON OF THE CARBON AND PHOSPHORUS REACTIONS

During iron refining virtually all the silicon and a considerable proportion of the manganese will be oxidized before any appreciable amount of phosphorus or carbon is removed. Consequently, the influence of slag composition and temperature on the carbon and phosphorus reactions may be regarded as the determining factors.

In the refining of high-phosphorus iron, a slag with a reasonably high $P_2O_5$ content, suitable for sale as fertiliser, will be demanded on economic grounds, and this will impose restrictions on the working temperature and slag composition. Furthermore, if the refined iron is for subsequent use in fixed open-hearth furnaces every advantage will attend the production of metal with a low phosphorus content.

A comparison of the carbon and phosphorus reactions is possible using the physico-chemical data given in the preceding section. At this stage, however, an explanation of the procedure to be adopted is scarcely possible in general terms, as too many symbols would be involved and the issue would be rendered unnecessarily complicated. In the following paragraphs special cases have been considered by way of example but the method can be applied to suit other cases.

### I—*The Refining of 2% Phosphorus Iron*

The requirements for the refining reaction to occur are :

(*a*) The metal must be liquid, *i.e.*, above, say, 1150° C.

(*b*) The slag must be fluid—the slag specified has a melting point in the neighbourhood of 1490° C.

TABLE I—*Slag Weight and Composition (Case I)*

| Element | % Removed from Metal | Weight Lost to Slag, *S*, cwt. | | Lime Required, *L*, cwt. | |
|---|---|---|---|---|---|
| Si | 0·70 | $SiO_2$ | 45 | 2 CaO . $SiO_2$ | 84 |
| Mn | 0·60 | MnO | 23 | ... | ... |
| P | 1·75 | $P_2O_5$ | 120 | 4 CaO . $P_2O_5$ | 188 |
| C | 0·60 | ... | ... | ... | ... |
| S | 0·07 | S | 2 | CaS | 4 |
| V | 0·10 | $V_2O_5$ | 5 | 4 CaO . $V_2O_5$ | 6 |
| | | Total | 195 | Total | 282 |

| Other constituents assumed present in slag | FeO, % | $Fe_2O_3$, % | Lime as 2 CaO.$Fe_2O_3$, % | MgO, % | $Al_2O_3$, % | $TiO_2$, % | Total, % of slag |
|---|---|---|---|---|---|---|---|
| | 10·5 | 3·3 | 2·3 | 4·0 | 2·0 | 0·5 | 22·6 |
| Remainder ($S + L$) of slag | 195 + 282 = 477 cwt. | | | | | | 77·4% |
| Gross slag weight | 616 cwt. | | | | | | 100% |

| Total concentrations, % | ($\Sigma SiO_2$) | ($\Sigma CaO$) | ($\Sigma P_2O_5$) | (CaO)′ | ($\Sigma MnO$) | ($\Sigma Fe$) | [$\Sigma C$] | [$\Sigma P$] |
|---|---|---|---|---|---|---|---|---|
| | 7·3 | 48·1 | 19·5 | 17·5 | 3·7 | 10·5 | 2·4 | 0·25 |

(*c*) There should be a slight oxidation of carbon, liberating carbon monoxide gas to give some motion to the metal to promote the slag/metal reaction. To retain the required carbon in the metal the rate of carbon fall should not exceed 0·001% /min.

It is assumed that a 150-ton furnace is available and that the compositions of the metal before and after refining are :

| | Si, % | Mn, % | P, % | C, % | S, % | V, % |
|---|---|---|---|---|---|---|
| Blast-furnace iron ... | 0·7 | 0·8 | 2·0 | 3·0 | 0·10 | 0·15 |
| Refined iron ... | Nil | 0·2 | 0·25 | 2·4 | 0·03 | 0·05 |

*Slag Formation*

On the basis of 150 tons of blast-furnace iron the final slag weight and composition may be calculated as shown in Table I.

*Affinities of the Phosphorus Reaction*

The values of (FeO) and (CaO) vary with temperature, as shown in Fig. 4, which is based on the total concentrations evaluated in Table I and the use of charts III to V of Schenck. The affinity values at four different temperatures have been calculated from equation (5) and the results are shown in Table II.

*Affinities and Rates of Removal for the Carbon Reaction*

After calculating the FeO in the metal at the four temperatures given in Table II the affinities of the carbon reaction have been evaluated as shown in Table III. The rate of carbon removal for each temperature has also been recorded using

TABLE II—*Affinities of the Phosphorus Reaction (Case I)*

| Temperature, ° C. | 1427 | 1527 | 1627 | 1727 |
|---|---|---|---|---|
| P in metal, *a*, % ... ... ... ... ... ... | 0·25 | 0·25 | 0·25 | 0·25 |
| (FeO) in slag, *b*, % ... ... ... ... ... | 3·32 | 5·90 | 8·46 | 11·05 |
| (CaO) in slag, *c*, % ... ... ... ... ... | 9·30 | 11·30 | 13·26 | 15·29 |
| ($\Sigma P_2O_5$) in slag, *d*, % ... ... ... ... ... | 19·5 | 19·5 | 19·5 | 19·5 |
| Affinity per 5 mol (FeO), $-\Delta G_P$, cal. ... ... ... | 9076 | 8766 | 5352 | 746·3 |
| Affinity per mol (FeO), $A_P$, cal. ... ... ... ... | 1815 | 1753 | 1070 | 145 |

TABLE III—*Affinities and Rates of Carbon Removal for the Carbon Reaction (Case I)*

| Temperature, ° C. | 1427 | 1527 | 1627 | 1727 |
|---|---|---|---|---|
| (FeO) in slag, $b$, % | 3·32 | 5·90 | 8·46 | 11·05 |
| Partition coefficient, $L_{FeO}$ | 0·00460 | 0·01048 | 0·01636 | 0·02220 |
| C in metal, $e$, % | 2·4 | 2·4 | 2·4 | 2·4 |
| [FeO] in metal, $f$, % | 0·015 | 0·062 | 0·139 | 0·245 |
| Affinity per mol [FeO], $-\Delta G_C$, cal. | 4753 | 9463 | 12332 | 14677 |
| Affinity per mol (FeO), $A_C$, cal. | 22 | 99 | 202 | 326 |
| $k_1$ [C] | 0·264 | 0·264 | 0·264 | 0·264 |
| $k_2 p_{CO}$ | 0·00382 | 0·00382 | 0·00382 | 0·00382 |
| Rate of carbon removal, $v$, %/min. | 0·0002 | 0·0125 | 0·0327 | 0·0609 |

the values of $k_1$[C] and $k_2 p_{CO}$ for a carbon content of 2·4% given by Fig. 1.

*Conclusions*

The variation with temperature of the affinity ($A_P$) of the phosphorus reaction, the affinity ($A_C$) of the carbon reaction, and the rate of carbon removal, are shown graphically in Fig. 5. From an examination of this diagram, and taking into consideration the fact that a slag of the type described has a freezing point of approximately 1490° C., the following deductions can be made:

(1) Phosphorus removal will take place up to 1740° C., at which temperature equilibrium will be reached with a phosphorus content of 0·25%.

(2) Above 1710° C. carbon oxidation will occur preferentially.

(3) Above 1500° C. the rate of carbon removal will exceed 0·007%/min. and the finishing carbon will be lower than the stipulated 2·4%.

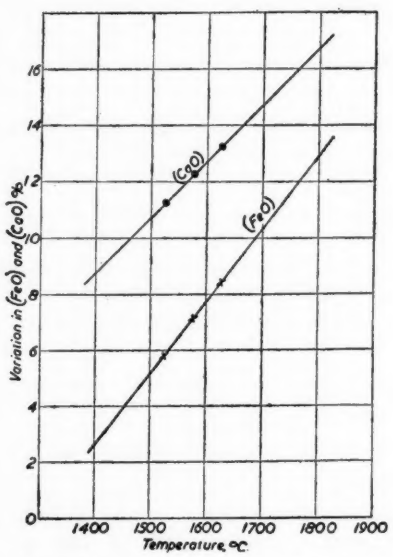



FIG. 4—Approximate variation in (FeO) and (CaO) with temperature in case I (based on Schenck's charts)

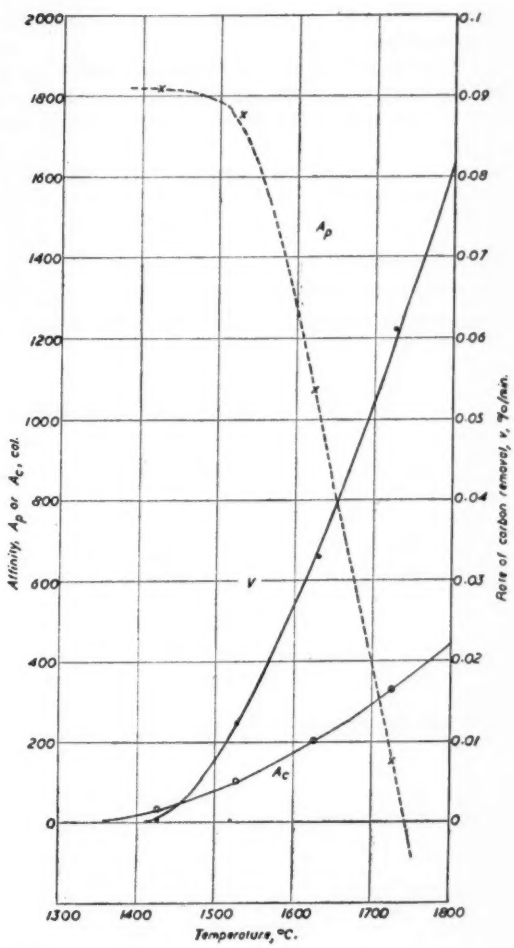



FIG. 5—Variation with temperature of $A_P$, affinity of phosphorus reaction, $A_C$, affinity of carbon reaction, and $v$, rate of carbon removal, in case I

(4) The latitude of refining temperature is too narrow to permit of operation on a practical scale. (The freezing point of a slag of this type was found to be 1490° C.)

(5) In the Bertrand Thiel and Hoesch processes higher silica contents and lower total iron contents in the final slags are to be found than in the slag described and the final carbon contents usually lie between 1·3 and 1·8%. This fact tends to confirm the above deductions.

### II—*The Refining of 0·84% Phosphorus Iron*

It should be possible to refine iron from 2·0% of phosphorus down to a value in the region of 0·25% of phosphorus with little loss in carbon if two or more refining slags are used. The freezing point of these slags would require to be in the region of 1400° C. and temperature control carefully exercised so that the rate of carbon removal would only be sufficient to keep the bath gently agitated.

It is assumed, as in the previous case, that a 150-ton furnace is available but that the compositions of the metal before and after refining are as follows :

| | Si, % | Mn, % | P, % | C, % | V, % |
|---|---|---|---|---|---|
| Blast-furnace iron ... | 0·7 | 0·8 | 0·84 | 3·0 | 0·15 |
| Refined iron ... ... | Nil | 0·5 | 0·25 | 2·8 | 0·05 |

#### *Slag Formation*

The final slag weight and composition may be calculated as shown in Table IV. No doubt a small amount of silicon will remain in the final metal after refining. This small error will, however, be outweighed by the silica in the feed materials and the silica arising from the furnace refractories. In actual practice allowances for these and similar effects would of course have to be made.

From the results obtained in case I the following steps have been considered essential :

(1) Lowering the freezing point of the final slag by raising the silica, alumina, and magnesia contents.

(2) Reduction of the $P_2O_5$ content of the slag to the order of 12·5%. A slag of this type should still be suitable as a fertiliser.

(3) Maintaining the total iron content of the slag at a lower value in order to achieve a low rate of carbon removal.

#### *Variation in (FeO) and (CaO)*

Since the values for (FeO) and (CaO) are raised to the fifth and fourth powers respectively in the calculations, greater accuracy has been attempted in determining the effect of temperature on these variables. In Figs. 6 and 7 the variations with temperature based on charts III to V of Schenck are shown. Figure 6 (*a*) illustrates the variations in (FeO) with (ΣFe) at different temperatures, the curves for 1427° C. and 1477° C. having been drawn in to correspond with the others. By reading off the values of (FeO) at 6·84% (ΣFe),

TABLE IV—*Slag Weight and Composition (Case II)*

| Element | % Removed from Metal | Weight Lost to Slag, *S*, cwt. | | Lime Required, *L*, cwt. | |
|---|---|---|---|---|---|
| Si | 0·70 | $SiO_2$ | 45·0 | 2 CaO . $SiO_2$ | 84 |
| Mn | 0·30 | MnO | 11·6 | ... | ... |
| P | 0·58 | $P_2O_5$ | 39·9 | 4 CaO . $P_2O_5$ | 63 |
| V | 0·10 | $V_2O_5$ | 5·4 | ... | ... |
| | | Total | 101·9 | Total | 147 |

| Other constituents assumed present in slag | FeO, % | $Fe_2O_3$, % | $Al_2O_3$, % | MgO, % | $TiO_2$, % | Total, % of Slag |
|---|---|---|---|---|---|---|
| | 7 | 2 | 6 | 7 | 1 | 23 |
| Remainder (*S* + *L*) of slag | 101·9 + 147 = 248·9 cwt. | | | | | 77 |
| Gross slag weight | 323·3 cwt. | | | | | 100 |

| Total concentrations, % | (Σ$SiO_2$) | (ΣCaO) | (Σ$P_2O_5$) | (CaO)′ | (ΣMnO) | (ΣFe) | [ΣC] | [ΣP] |
|---|---|---|---|---|---|---|---|---|
| | 13·9 | 45·5 | 12·3 | 26·8 | 3·6 | 6·84 | 2·8 | 0·25 |

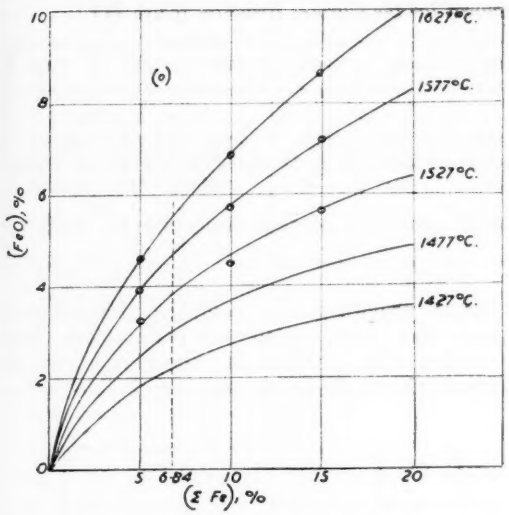



FIG. 6—(*a*) Variation in (FeO) with (ΣFe) in case II

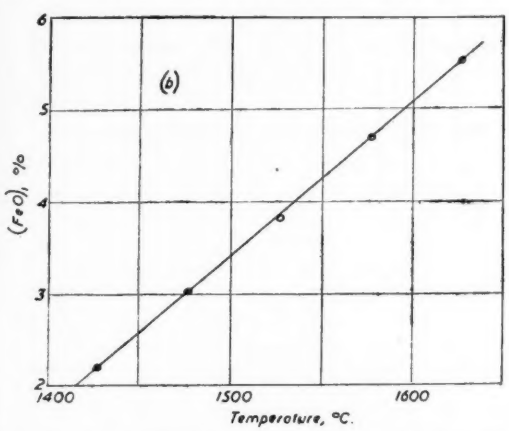



FIG. 6—(*b*) Approximate variation in (FeO) with temperature at 6·84% (ΣFe)

Fig. 6 (*b*) was constructed and the variation in (FeO) with temperature was found to be

$$(FeO) = 0{\cdot}0168t - 21{\cdot}78 \quad \ldots\ldots\ldots\ldots\ldots\ldots (15)$$

Figures 7 (*a*) and 7 (*b*) were constructed in a similar manner and the variation in (CaO) found

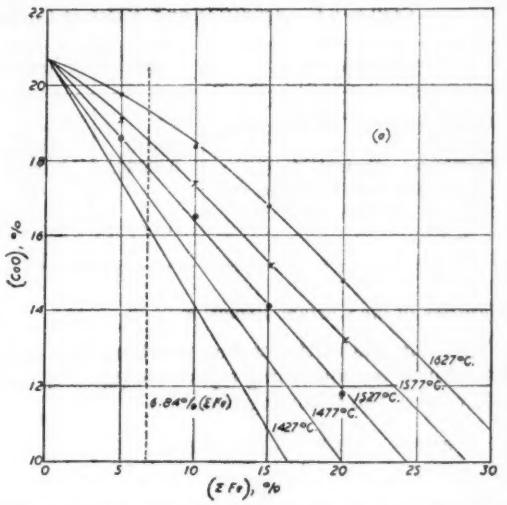



FIG. 7—(*a*) Variation in (CaO) with (ΣFe) in case II

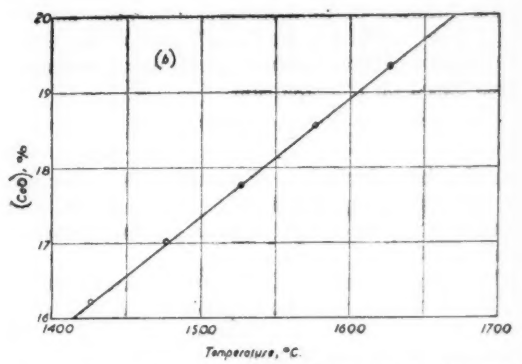



FIG. 7—(*b*) Approximate variation in (CaO) with temperature at 6·84% (ΣFe) in case II

to be represented by

$$(CaO) = 0{\cdot}01556t - 6{\cdot}0 \quad \ldots\ldots\ldots\ldots\ldots\ldots (16)$$

### *Affinities of the Phosphorus Reaction*

By substituting the appropriate values in equation (5) the affinities of the phosphorus reaction at different temperatures have been determined, the results being shown in Table V.

TABLE V—*Affinities of the Phosphorus Reaction (Case II)*

| Temperature, °C. | 1427 | 1527 | 1627 | 1727 |
|---|---|---|---|---|
| P in metal, *a*, % ... ... ... ... | 0·25 | 0·25 | 0·25 | 0·25 |
| (FeO) in slag, *b*, % ... ... ... ... | 2·2 | 3·84 | 5·52 | 7·22 |
| (CaO) in slag, *c*, % ... ... ... ... | 16·2 | 17·77 | 19·33 | 20·90 |
| ($\Sigma P_2O_5$) in slag, *d*, % ... ... ... ... | 12·3 | 12·3 | 12·3 | 12·3 |
| Affinity per 5 mol (FeO), $-\Delta G_P$, cal. ... | 11,260 | 9202 | 4717 | −906 |
| Affinity per mol (FeO), $A_P$, cal. ... ... | 2252 | 1840 | 943 | −181 |

TABLE VI—*Affinities and Rates of Carbon Removal for the Carbon Reaction (Case II)*

| Temperature, ° C. | 1400 | 1420 | 1440 | 1450 | 1470 | 1500 | 1600 | 1700 |
|---|---|---|---|---|---|---|---|---|
| Affinity per mol [FeO], $-\Delta G_C$, cal. | 3040 | 4215 | 5245 | 5715 | 6590 | 7725 | 10,740 | 13,000 |
| Partition coefficient, $L_{FeO}$ | 0·00302 | 0·0042 | 0·00537 | 0·00596 | 0·00714 | 0·00890 | 0·01478 | 0·02066 |
| Affinity per mol (FeO), $A_C$, cal. | 9 | 18 | 28 | 34 | 47 | 69 | 159 | 269 |
| Rate of carbon removal, $v$, %/min. | −0·00152 | −0·00057 | 0·00058 | 0·00124 | 0·00272 | 0·00533 | 0·0175 | 0·0340 |

*Affinities of the Carbon Reaction*

The affinities of the carbon reaction have been determined by combining equations (9), (13), and (15) to give the following equation :

$$-\Delta G_C = 4{\cdot}573T\left[\frac{2400}{T} + 0{\cdot}675 - \log\frac{0{\cdot}3928}{(0{\cdot}0168t - 21{\cdot}78)(0{\cdot}588 \times 10^{-4}t - 0{\cdot}0793)}\right] \quad (17)$$

In this way the calculation of the affinities for a larger number of temperatures has been simplified. The results are shown in Table VI in which the rate of carbon removal at different temperatures based on the equation

$$v = 0{\cdot}2667 \times 10^{-6}t^2 - 7{\cdot}05 \times 10^{-4}t + 0{\cdot}46275 \quad \ldots\ldots(18)$$

has also been included. Equation (18) is formed by combining equations (7), (11), and (15) and using the values of $k_1[C]$ and $k_2 p_{CO}$ for a carbon content of 2·8% given in Fig. 1.

The negative values of $v$ at 1400° C. and 1420° C. will not obtain in actual practice ; $v$ will tend towards zero as $-\Delta G_C$ decreases and $P_{CO}$ will decrease at the same time.

*Conclusions*

The graphs representing the variation of $A_P$, $A_C$, and $v$ with temperature are shown in Fig. 8. The following deductions can be made :

(1) The necessary degree of dephosphorization should be achieved since equilibrium is only reached at a temperature of 1715° C.

(2) Preferential oxidation of phosphorus should occur up to a temperature of 1695° C.

(3) At 1470° C. the rate of carbon removal barely exceeds 0·002%/min. If this is considered the upper temperature limit during working and the average temperature is 1440°–1450° C. over the range 1390°–1470° C., the average rate of carbon removal should be about 0·001%/min. or 0·06%/hr.

(4) At 1500° C. the rate of carbon removal will be in the region of 0·005%/min. which will be indicated by a very vigorous boil.

(5) It would appear to be technically possible to refine high-phosphorus iron with little loss in carbon providing close control of temperature and slag composition be maintained. The smaller the amount of phosphorus to be removed and the greater the permissible carbon

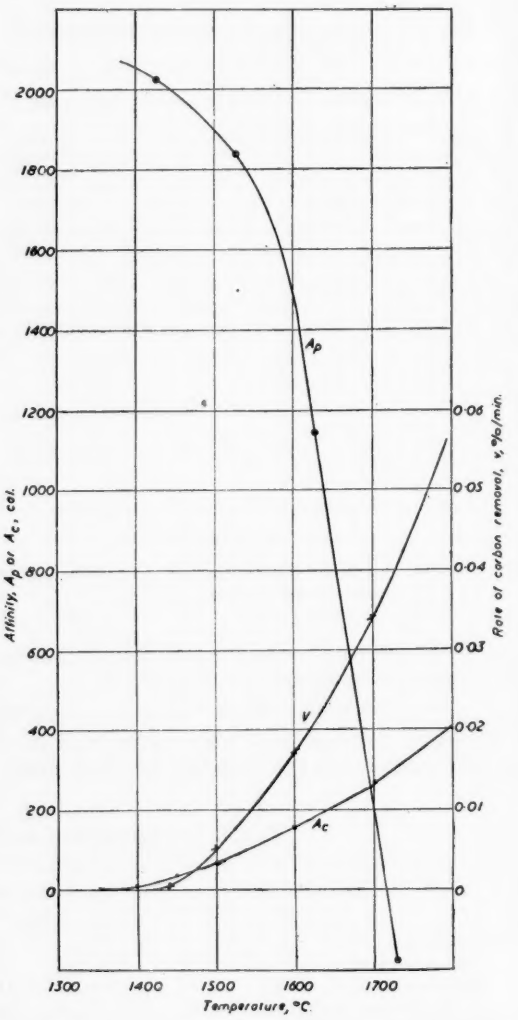



FIG. 8—Variation with temperature of affinity $A_P$, affinity $A_C$, and rate of carbon removal $v$, in case II

TABLE VII—*Oxide Requirements (Case II)*

| Constituent | Si | Mn | P | C | V |
|---|---|---|---|---|---|
| % Removed ... ... ... ... | 0·70 | 0·30 | 0·58 | 0·20 | 0·10 |
| Carbon equivalent, % ... ... ... | 0·60 | 0·06 | 0·56 | 0·20 | 0·06 |
| Total carbon equivalent ... ... ... | | | | 1·48 | |

% Carbon equivalent oxidized per hr. $= \frac{1·48}{3·3} = 0·448$

Assume furnace oxidation* $= 0·14\%$/hr.

Carbon equivalent for removal by oxide $= 0·448 - 0·140 = 0·308\%$/hr.

Oxide required $= 0·308$ cwt./ton/hr. $= 46·2$ cwt./hr.

* Bacon[5] quotes a figure of 0·16 cwt. of oxide/ton/hr. for normal open-hearth working (0·16 cwt. of oxide/ton/hr. is approximately 0·16% of carbon/hr.)

drop the wider will be the range of working temperature and the easier the control of the process.

## PRACTICAL CONSIDERATIONS

In considering the practical aspects of the refining of high-phosphorus iron case II will be taken as an example.

### *Oxide Requirements and Processing Time*

In order to maintain the necessary degree of agitation of the bath and rate of oxidation of the metalloids the rate of carbon removal should be controlled at approximately 0·001%/min. during the course of refining. The time during which the refining should be completed can, therefore, be calculated from the loss in carbon. The refining time necessary for a carbon drop of 0·2% becomes

$$0·2/(0·001 \times 60) = 3·3 \text{ hr.}$$

The metalloids may be reckoned in terms of carbon equivalent during oxidation and the oxide requirements evaluated in Table VII.

It is obvious that, in actual practice, great difficulty would be encountered in feeding the oxide at 46 cwt./hr. The process would, therefore, need to be lengthened according to the type and performance of the furnace used, and consequently the carbon in the blast-furnace iron would require to be higher in order to finish the refining with the required carbon content.

With a carbon content in the blast-furnace iron of 3·25% the process could be extended to $7\frac{1}{2}$ hr. and the carbon removal maintained at 0·001%/min. Under these conditions the oxide feed would only require to be at the rate of 13·5 cwt./hr. for the 150-ton charge and the refining rate would be 20 tons/hr.

The rate of oxide feed may be adjusted to give the necessary output, depending on the hot-metal requirements of the open-hearth plant, but it should be kept at a minimum in order to prevent a sudden rise in the iron content of the slag which would cause a vigorous bath reaction and large drop in carbon. However, during the early stages of refining, when largely the silicon is being oxidized and the bath temperature is rising fairly rapidly, a greater rate of oxide feed is possible, if not necessary, to help to flux the lime additions. The amount of oxide to be fed in during this period can be gauged from the silicon content of the iron. For example if, as in case II, 0·7% of silicon is to be removed in a 150-ton bath, 89 cwt. of oxide will be required to form $SiO_2$.

### *Continuous Working*

Under certain circumstances it may be necessary to add unrefined iron to the refined mixer metal after having withdrawn some of the latter for steelmaking and to repeat this procedure periodically, according to the supply of iron from the blast-furnaces and the demands of the open-hearth furnaces. If a mixer output of 20 tons/hr. is required then the oxide can be added at the rate of 13·5 cwt./hr. after the first 150 tons have been refined.

### *Refining Practice*

During the initial stage of refining it should be possible to accelerate the removal of silicon without adversely affecting the rate of carbon removal because of the much greater affinity of the silicon reaction. Consequently, the maximum oxide feed should be made during the initial period of silicon removal, when the bath temperature is rather low, and the lime charge should be reduced to a minimum in order to maintain a low slag volume and assist heat transfer to the bath.

Difficulty will, no doubt, be experienced in initiating the formation of a fluid slag, particularly during the first hour of refining, and the addition

of some 5 cwt. of alumina in the form of bauxite will be of assistance. The empirical formula

$$Al_2O_3 + SiO_2 + FeO + P_2O_5 > 35\%$$

should be useful in indicating the feed requirements in order to maintain a fluid slag.

The presence of lumps of lime floating on the bath surface is regarded as desirable during the early stages of slag formation and a proportion of limestone in the charge should be of advantage in keeping the bath open and in acting as an oxidizer because of the formation of carbon dioxide.

Towards the end of silicon removal more alumina as well as some magnesia in the form of crushed doloma might be added. A rapid determination of the total iron content of the slag will indicate the amount of oxide required and a sudden rise in $P_2O_5$ content will indicate the end of silicon removal and the beginning of phosphorus oxidation. At this stage, therefore, a close control of temperature and basicity will be necessary and steps should be taken to feed as much lime as possible aiming at the predetermined final slag composition.

During phosphorus removal precautions should be taken to prevent the bath temperature rising above the limiting temperature (say 1470° C.) necessary for rapid phosphorus removal and a low rate of carbon removal. The appearance of the bath should give some indication of the rate of carbon removal and rapid check carbon and phosphorus determinations might well be carried out as and when the opportunity occurs.

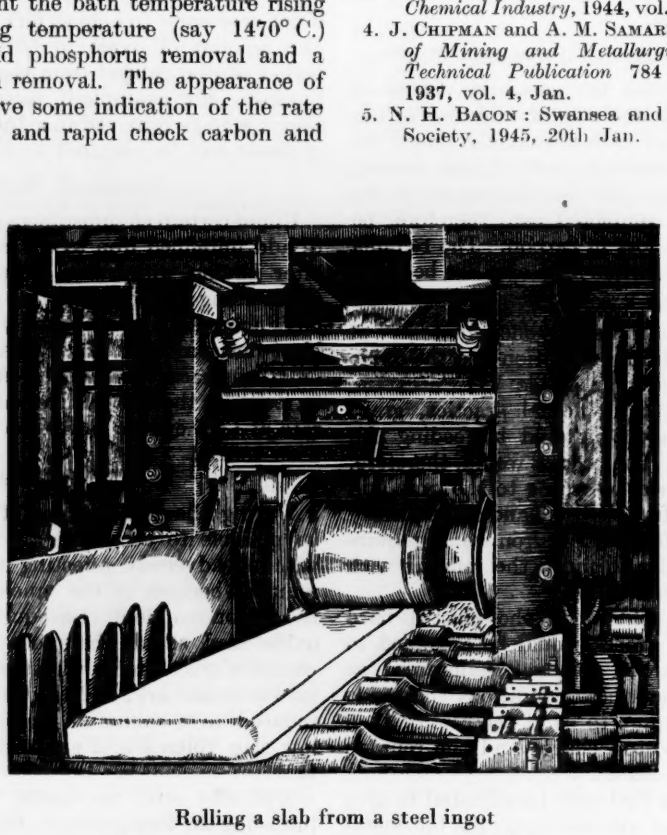
In the case of high-phosphorus iron of the order of 2% phosphorus (*see* I) it will be necessary to carry out the refining in two or three stages whereby the phosphorus content is reduced by approximately 0·6% in the first stage and, after slagging off, a further slag is built up and more phosphorus removed. Subsequently the refining may be carried on continuously by adding more blast-furnace iron periodically but the refining time will depend largely on the permissible carbon drop and the amount of phosphorus to be removed.

### Acknowledgments

The author wishes to express his thanks to the Management, Messrs. Stewarts and Lloyds, Ltd., for permission to publish this paper. Thanks are also due to Mr. W. C. Bell and Dr. T. P. Colclough for their interest and encouragement.

### References

1. H. Schenck : "Physical Chemistry of Steelmaking," 1945 : British Iron and Steel Research Association.
2. Y. K. Zea : *Journal of the Iron and Steel Institute*, 1945, No. I, pp. 459p–504p.
3. H. J. T. Ellingham : *Journal of the Society of Chemical Industry*, 1944, vol. 63, May, pp. 125–133.
4. J. Chipman and A. M. Samarin : *American Institute of Mining and Metallurgical Engineers*, 1937, *Technical Publication* 784 : *Metals Technology*, 1937, vol. 4, Jan.
5. N. H. Bacon : Swansea and District Metallurgical Society, 1945, 20th Jan.



**Rolling a slab from a steel ingot**
**From the original woodcut by Viva Talbot**

# A Note on Variations in Producer-Gas Quality*

*By J. E. de Graaf*†

SYNOPSIS

*An account is given of some factors—including the tar content and humidity—and their variations which influence the quality of producer gas. The quality of the gas is improved by high volatile-matter content, high fusion point of the ash, etc., but especially by avoiding fines in the coal. The operation of the producer is also considered, and the influences of throughput, channelling, etc., are ascertained. Approximate rules are given for adapting the steam/air ratio to varying conditions,* e.g., *properties of the coal.*

## INTRODUCTION

THE conditions prevailing during the years 1940–1945 were such as to permit the collection of a large amount of information on the factors which influence the quality of the gas, and its variations. Even under favourable conditions the quality of the gas can change rapidly, although the operations may be carefully controlled. Quality is denoted here as all the properties which are important in open-hearth firing, thus including the composition, the tar content, and the humidity.

A knowledge of the variations in these properties can not only be an advantage to secure a high quality gas, and thus a high speed of steel production, but also fuel economy. It proved, also, to be very useful in investigations of the open-hearth furnace, in which many variations were found, some of which, at least, could be attributed to variations in gas quality. Thereby the reliability of the open-hearth investigations could be enhanced, which was in fact the main purpose of the examination of producer-gas quality at the time it was performed.

Most of the information was obtained with gas producers serving an open-hearth shop, the producers being of the mechanical type with levelling devices. Their internal diameter was 11 ft. The coal was fed continuously along a radius of the rotating shell. The air was blown in by a separate fan for each producer, thus not relying on the injection by the steam. This allowed the independent regulation of steam and air, as well as exact metering of both. In this way the usual and sometimes very large errors were avoided, which are made when the so-called saturation temperature is used. For comparison purposes some information was collected on hand-operated producers supplying gas for a sheet mill plant. Here the coal was fed intermittently; the internal diameter was about 8½ ft.

The bituminous coal was of Dutch and (largely) of German origin, varying considerably in properties‡:

| | | |
|---|---|---|
| Volatile matter | ... ... | About 23–41% |
| Ash... | ... ... ... | „ 3–11% |
| Moisture | ... ... ... | „ 1–7% |
| Oxygen | ... ... ... | „ 4–11% |
| Hydrogen | ... ... ... | „ 4·1–5·5% |
| Fusion point of ash | ... | 1150°–1370° C. |

An exceptional difficulty, which hampered investigations and perhaps sometimes reduced the reliability of the results, was that optimum conditions as derived from the experiments could not be put to the test for long periods, as under the conditions prevailing any increase in steel production was undesirable.

## VARIATIONS IN TAR CONTENT OF THE GAS

As rather strong variations in luminosity of the flame in open-hearth furnaces were noticed, which could not be attributed, *e.g.*, to varying preheat, and as tar is known to be very important in this respect, it was considered necessary to accumulate data on tar content of the gas, and to develop an easy means for determining this constituent. It was assumed that the tar (and oils) were present as vapour, for on opening a hole in the gas main, dispersion of light from a beam through and perpendicular to the stream of gas was noticed only at some distance from the hole (Tyndall effect). This means that droplets would be formed only after some cooling, and thus that tar was present as a vapour. This condition existed as far as the regenerators of the open-hearth furnaces, where the gas temperature was lowest, *i.e.*, about 450° C. as measured with a suction pyrometer.

* Received 27th February, 1947.

† Koninklijke Nederlandsche Hoogovens en Staalfabrieken, N.V., Ijmuiden, Holland.

‡ Determined according to Dutch standards, which deviate only in minor details from the American procedure.

### *Method of Sampling*

When tar is present as a vapour, sampling is simple, as speed and direction of sampling are far less critical than in the case of fine droplets. This was substantiated by taking samples at the same time and at the same spot in the main, with speeds in the sampling tubes varying from 0·13 to 16 ft./sec., whilst in the mains the speed of the gas was about 3 ft./sec. (at N.T.P.). Slight variations in tar content were found (about 0·5 grains/cu. ft. on an average of about 7 grains/cu. ft.) which could not, however, be correlated to the speed of sampling, and thus were considered to show the accuracy of the tar determination itself. The material of the sampling tube was usually silica, though no differences between silica, copper, or iron were found. The only requirement for the sampling tube was that its tip should be so far in the gas stream as to nearly attain the temperature of the gas, thereby avoiding the condensation of tar at the entrance of the tube.

Connected to the tube outside the main was a filter consisting of a glass tube about 1 in. wide in which was packed clean sand between asbestos wool. The distance between the wool discs was about $1\frac{1}{2}$ in.; a greater distance did not increase the amount of tar caught. Behind this filter some white wool was packed which should not show any discoloration. Through the sampling tube and filter about 0·35 cu. ft. of gas were sucked in about 10 min., at a speed sufficiently low to avoid any noticeable rise in temperature of the filter.

After taking the sample, the sampling tube and the filter were wiped clean on the outside and then dried until weight constancy was achieved by rinsing with dry air at 60° C. Drying in an oven at 100° C. did not result in a greater loss of weight than in the air drying. The tar and oils were then removed by dissolving in benzene; the benzene flowing in the same direction as previously the gas did. In this way any removal of soot was avoided, as was proven by the absolutely clean solution obtained. After renewed drying, the weight difference was considered to represent tar and oils. If required, the carbon remaining in the filter, *i.e.*, the soot, could be determined, *e.g.*, by combustion.

As in preliminary experiments large variations in tar content were found, it was necessary to make sure that this was neither due to the method of filtering or of determining the weight of the tar, nor to inhomogeneity of the gas stream in the main. The first source of error could be excluded by the experiments mentioned in which samples were taken simultaneously at the same spot, giving differences of about 0·5 grains/cu. ft. The second source of error was practically excluded by taking samples simultaneously at a number of points across the diameter of the main. Differences of about 1 grain/cu. ft. were found. From this it was concluded that the method was sufficiently accurate for our purposes.

### *The Effect of Various Factors on Tar Content of the Gas*

In the preliminary experiments the tar content was found to vary at random between 2·5 and 12 grains/cu. ft. during periods in which every factor, including the coal composition, seemed constant. It was therefore decided to tackle the problem statistically, and thus during a period of about 90 hr. four samples per hour were taken for tar-content determination, whilst at the same time the coal was sampled by emptying a predetermined part of a compartment of the feeder drum, thereby ensuring that a true sample was obtained. Simultaneously, the volumes of air and steam, the amount of coal fed, and the gas temperature (by means of a suction pyrometer) were measured. For practical reasons the samples of coal were mixed to form representative samples of $3\frac{1}{2}$-hr. runs from which sieve analysis, ash, and volatile matter were determined.

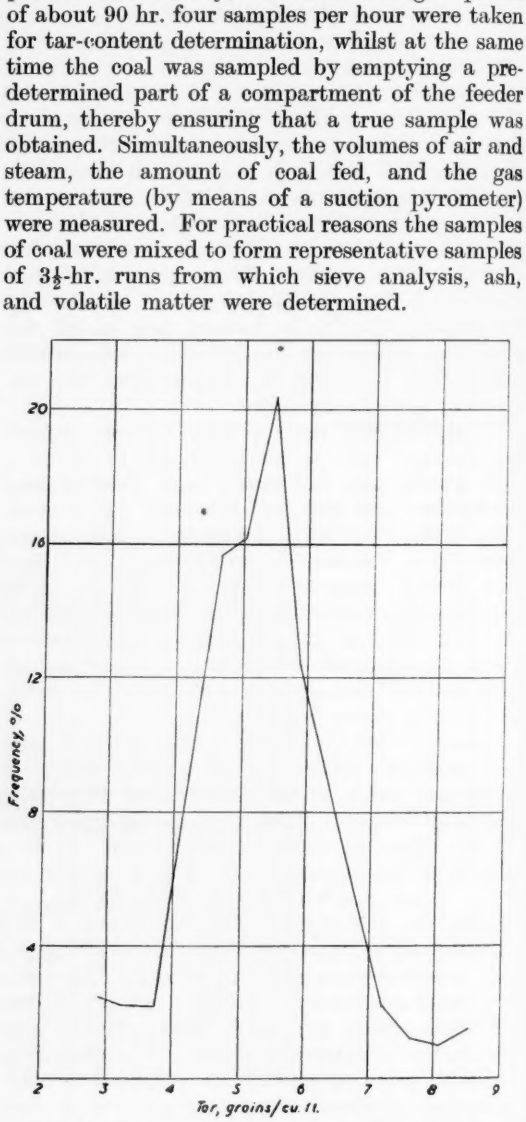



FIG. 1—Diagram representing the variations in tar content during a 90–hr. period

The variation of the tar content during the 90-hr. period is shown in Fig. 1. The large variations during a period in which every controllable factor was kept constant, show that variations in tar content could be an important reason for the variations in luminosity of open-hearth flames. It should be mentioned here that the coal used in these experiments was of rather low quality (coal *WV*, with 30% of volatile matter). With well screened coal of high quality, *e.g.*, coal *FL* with 39% of volatile matter, the average can be about 9 or 10 grains/cu. ft., with smaller variations (± 1·5 grains/cu. ft.) about this average.

No correlation was found between the tar content of the gas and the ash content of the coal, presumably because the variations in ash content were small (5·3–5·9%). A slight correlation was found between tar content and gas temperature; about 0·2 grains/cu. ft. per 10° C. variation. As the gas temperature varied between 680° and 830° C., which includes the variations due to poking (the normal temperature was 750° ± 25° C.), this could account only for a small part of the total tar variation observed, and in the following, reasons will be found for attributing both fluctuations to one common cause, *i.e.*, fines in the coal. Another correlation was found between tar content of the gas and volatile-matter content of the coal. Together with data of determinations of tar content when other coals were gasified, an average variation value of 0·4 grains/cu. ft. per 1% of volatile matter was found. As the volatile-matter content of the coal varied during the 90-hr. period, from 30·4 to 28·9%, this accounts for a variation of 0·6 grains/cu. ft. In fact the slightly unsymmetrical form of the frequency curve in Fig. 1 is due to a slow but continuous variation of volatile-matter content in the coal. Although in this experiment the influence of varying volatile-matter content on tar content was slight, in the course of all our experiments the coals varied in volatile-matter content from about 23% to about 40%, and thus large variations of tar content were found of between about 3 and 10 grains/cu. ft. as averages for periods in which the same coal was gasified. Such variations, of course, show very strongly in the luminosity of the flame, and even variations of a few per cent, which can readily occur in one consignment of coal, can be felt in steel production.

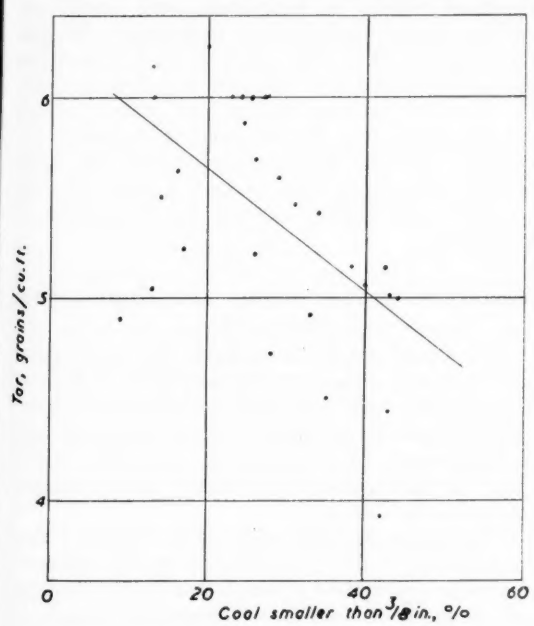



FIG. 2—The effect on the tar content of the percentage of fines in the coal

The most important correlation was the effect on tar content of the percentages of fines in the coal (Fig. 2), *i.e.*, coal smaller than $\frac{3}{8}$ in. It would seem from this graph that the fines produced about half as much tar as compared with that produced from coarse coal. The volatile-matter content of the fines was, however, only one seventh lower than that of the coarse coal. As the volatile-matter content is not an entirely reliable indication of tar produced, samples of fine and coarse coal were subjected to a distillation process at 700° C. in a stream of nitrogen. The samples were crushed to a size of about $\frac{1}{8}$ in. and introduced, in a boat, into a tube furnace. The boat was first kept in a cold part of the tube whilst the stream of nitrogen was turned on to remove the air from the tube, etc., and then the boat was pushed into the hot part (at 700° C.). The escaping tar was carried by the nitrogen through a filter of the same construction as used in the producer experiments. Although in this way nearly the same amount of tar was produced as in the gas producer, the difference between fine and coarse coal remained small, tar from the fines being now about one sixth lower than the tar produced from the coarse coal. It was found, however, that the speed of the stream of nitrogen had a strong influence on the tar produced, as a ten-fold decrease of the speed decreased the tar production to about half the original figure. It is felt that this gives the key to an explanation of the influence of fines in the producer. It seems probable that fine coal added to coarse coal increases the local variations in resistance,* and thus in speed of flow of the gas. A local increase in speed will have a slight influence (increasing the amount of tar carried away), but a local decrease in speed will be followed by a strong decrease in tar production, especially so in high-load producers in which the

* P. O. Rosin, cited by J. G. Bennett, *Journal of the Society of Glass Technology*, 1939, vol. 23, p. 164.

average gas velocity is already so high that an increase of this velocity does not increase substantially the amount of tar carried away.

This experience stresses again the well-known fact that screening or better classification of producer coal is necessary. This influence is to be distinguished from that studied by H. L. Saunders and R. Wild,* who were interested in 'macro-distribution' of the fine and coarse coal. It shows, too, that even small percentages of fines have an appreciable effect. There is a slight tendency to an increase in the amount of $CH_4$ and illuminants in the gas, but this does not counterbalance the loss of tar. This influence of the speed of the gas is also considered to be the reason for the relatively slight variation of tar production with throughput of the producer. With lower throughput a higher coal bed is permissible with, as a result, a slower rate of heating through the evaporation range of the newly fed coal, and thus a higher tar production, as is well known in low-temperature carbonization. This, however, is counteracted by the effect of the speed of the gas, resulting in an increase of about 0·2 grains/cu. ft. per decrease of 10,000 cu. ft. of air per hour, under our conditions. Of course, channelling has a detrimental effect due to the same cause, as formation of channels means a decreased speed of flow through the other portions of the bed. This cause of fluctuating tar content was very nearly avoided, in the statistical experiment described, by exceptionally careful operation, but in normal operation it decidedly has an influence, as it can readily cause a decrease of 2 grains/cu. ft. in the gas in the mains.

It could be assumed that the variations in hydrocarbon content would be decreased at the entrance to the open-hearth furnace because soot is deposited in the mains and perhaps in the regenerators, which deposits would increase with an increased amount of hydrocarbons in the gas. Microscopic investigation of the soot from the main revealed, however, that it consisted largely of coke particles with only a very thin layer of lampblack in dendritic form. Estimations of the total amount of lampblack in the mains showed that a change of gas composition, including tar, would be nearly imperceptible. This was confirmed by simultaneously taking samples just after the producer, after the dustcatcher, and just before the regenerator. The main between the dustcatcher and the regenerator was an underground duct of 115 ft. in length. In the samples soot was determined also. It was assumed that lampblack could be determined with reasonable accuracy, as the size of the particles is very small. By sucking gas from the uptake of the open-hearth furnace through a vertical glass tube and then observing the speed of fall of the particles, a crude figure for their diameter could be obtained, assuming them to be compact balls of carbon. The diameter was about 0·4 μ. Particles of this size follow the stream of gas with fairly good approximation so that sampling can be fairly accurate. Table I gives the carbon in grains/cu. ft. of nitrogen in the gas as an average of five sets of observations at the places mentioned. It shows that the accuracy is not sufficient to reveal any loss of carbon in the main.

TABLE I—*Carbon Content of Gas (in grains/cu. ft. of Nitrogen) at Five Places of Observation*

| | After Producer | After Dust-catchers | Before Checkers | After Checkers |
|---|---|---|---|---|
| Total carbon | 165 | 166 | 163 | 162 |
| Carbon in hydrocarbons | 36·7 | 35·8 | 35·0 | 24·5 |
| Carbon as soot | ~1 | ~1 | ~1 | ~8 |

A certain decrease of carbon in the hydrocarbons is apparent, but this reappears mostly as carbon dioxide and carbon monoxide in the gas. The variations in hydrocarbon content thus appear undiminished at the checkers. In the series of samples were included samples from gas in the uptakes of the furnace. Through cracking, the amount of hydrocarbons is decreased, the carbon appeared partly as lampblack and partly as carbon dioxide and carbon monoxide. Within the accuracy of the determinations, a deposition of carbon in the checkers was not found. Only the reaction between carbon and water vapour can decrease the fluctuations of hydrocarbon content. Thus it can be concluded that variations of hydrocarbon production in the producer will be felt nearly undiminished in the luminosity of the flame.

## Variations in Composition and Humidity of the Gas

Rapid fluctuations occur also in the composition and humidity of the gas. Figure 3 gives an impression of such variations during a period of apparently constant operation. They are again sufficiently large to influence the properties of the flame in the open-hearth furnace, and to hamper investigations there.

The determinations made often included that of humidity. This was effected by the pressure/temperature method in which an arbitrary volume of the gas is enclosed in a vacuum-tight insulated vessel at a temperature above the dew point. Temperature and pressure in the vessel are noted

* H. L. Saunders and R. Wild, *Journal of the Iron and Steel Institute*, 1946, No. II, pp. 73–82P.

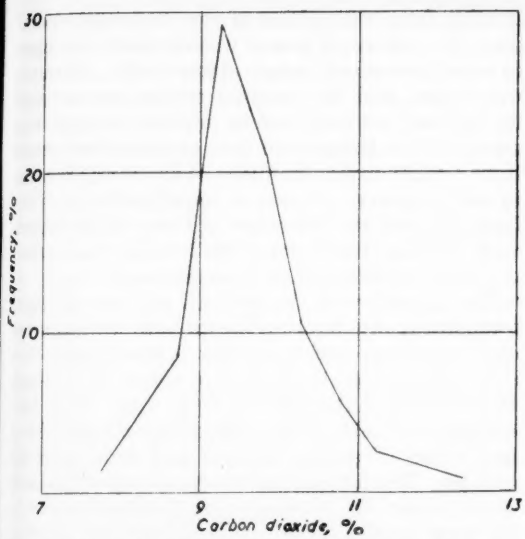



FIG. 3—Variations in carbon dioxide content during a period of constancy

after constancy has been reached, and then the vessel and gas are cooled below the dew point. Again temperature and pressure are read, and from the readings the humidity can be calculated. Usually instruments of this type which are specially suitable for dirty gases, are fitted with a heating element to bring the temperature of the vessel above the dew point. With hot producer gas this is not necessary as the gas can be used to flow through the vessel and through the space between vessel and insulation, thereby bringing vessel and insulation to the required temperature. If the initial temperature is not too high, *e.g.*, not above 120° C., no appreciable influence is found of the vapour of the tar or oils.

First it had to be ensured that the distribution of temperatures and of gas flow, as determined by grate and ash bed, were sufficiently regular as not to be a cause of fluctuations. The simplest way of checking this seemed to be by determining the humidity of the gas leaving the fuel bed at different points, as steam and air are mixed thoroughly before entering the producer. By means of a tube ending a few inches from the fuel bed, samples were taken of the gas. During sampling, the producer rotated so that the samples gave an average around the circumference of a circle with known radius. In this way local variations were prevented from giving an undue effect, and the true influence of grate and ash bed was determined. It was found that up to about 10 in. from the wall the humidity was practically constant, *i.e.*, it fluctuated not more than about 8% about the average. At the wall the humidity rose to 20 or 25% above the average. This was considered to be a sufficiently good distribution, the wall effect being unavoidable.

The gas from channels was sampled (*see* Table II). It is seen that humidity rises as sharply as tar content decreases, and also that the gas composition changes rapidly. As an average of determinations on gas in the main it was found that the variations of gas composition and humidity due to channelling could be expressed, per increase in humidity of the gas by 10 grains/cu. ft., as an increase of carbon dioxide by 1·4%, a decrease of tar content of about 3·2 grains/cu. ft., and a decrease of carbon monoxide and hydrogen by 2·7 and 1·4% respectively.

Even if channelling is avoided by extraordinary care and by a slightly higher steam/air ratio,* small irregularities in the gas flow occur. This happens especially, as was shown in the preceding section with respect to tar, when the percentage of fine coal is not negligible. These 'normal' fluctuations could not be determined with certainty, but as far as could be ascertained, the relations between water vapour, carbon dioxide, carbon monoxide, and tar given for channels were also suitable here. Fluctuations of humidity in a bed without visible channels, taken for a day or so, amounted to about 5 grains/cu. ft. The variation of hydrogen was smaller than in the case of channelling, being, presumably, less than half the value.

Rapid variations of the steam/air ratio are another cause of fluctuations in gas composition and humidity. Such variations of the steam/air ratio are due to variations in pressure or dryness of the steam, or to strong changes in humidity of the air (*e.g.*, fog). The variations often pass unnoticed, because often the instruments for determining the steam/air ratio are not sufficiently

* It should be noted that the term "steam/air ratio" is in common usage by operators, and implies the weight of steam, in grains, per cubic foot of air.

TABLE II—*Influence of Channelling on Gas Composition*

| | $H_2O$, grains/cu. ft. | Tar, grains/cu. ft. | $CO_2$, % | CO, % | $H_2$, % | $CH_4$, % | $C_nH_m$, % | $N_2$, % |
|---|---|---|---|---|---|---|---|---|
| Serious channel ... | 81 | ~1 | 15·7 | 7·3 | 4·3 | 0·3 | 0·4 | 72·0 |
| Channel just visible | 47 | ~2·5 | 10·8 | 17·6 | 10·3 | 1·0 | 0·6 | 60·2 |
| Good fuel bed ... | 30 | 6·5 | 5·5 | 26·0 | 15·0 | 2·9 | 1·3 | 49·3 |

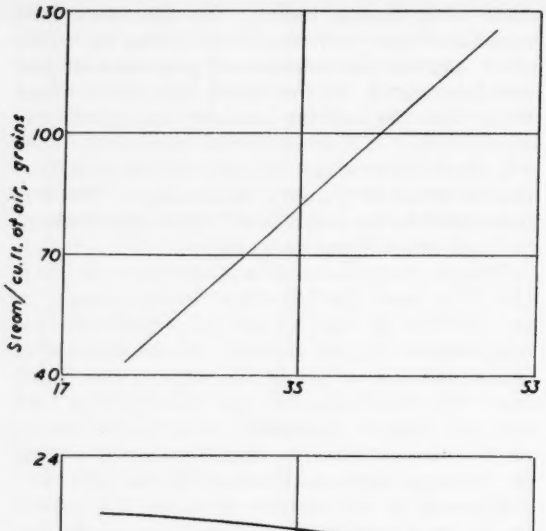



FIG. 4—The effect of an abrupt change of steam/air ratio on gas humidity and composition

sensitive. In the writer's opinion this is specially the case when the so-called saturation temperature is taken as a measure for the steam/air ratio, this method giving a very crude approximation of the real value. Figure 4 shows the variations of the gas composition and humidity when, starting from a condition of very constant operation, the volume of steam was abruptly changed to a predetermined value. After 6 min. a sample was taken, and the original conditions restored for at least 30 min. before another change was made. The changes in gas composition result from a fairly rapid alteration of the temperatures in the producer. Of course, equilibrium has not been reached and therefore the rise of hydrogen with increasing steam/air ratio is larger than when constant conditions had been attained.

The humidity of the gas can also be changed temporarily by blowing steam into the gas, as often happens during poking. This steam has some influence on the gas composition, as through the reaction $CO + H_2O \rightarrow CO_2 + H_2$, the concentration of carbon monoxide is slightly decreased and those of carbon dioxide and hydrogen increased. The influence on the gas composition was small under our circumstances, being about 1% for each of the constituents mentioned, per 40 grains of water per cubic foot. The major objection against this practice is, therefore, not the variation in gas composition, but the increased attack on soot in the regenerators.

Steam/air ratio variations of long duration, *i.e.*, when constant conditions are attained, have qualitatively the same effect as shown in Fig. 4, but the variations of carbon monoxide and carbon dioxide are larger and those of hydrogen smaller. Expressed again as variations per increase of 10 grains of water vapour per cubic foot, carbon dioxide increases by about 1%, carbon monoxide decreases by about 1·5%, and hydrogen increases by about 0·8%. Comparison with the data of Fig. 4 shows that even during 6 min. after a change in steam/air ratio is made, the adaptation of the producer, as expressed in the gas composition, has proceeded more than half way in the direction of the final constant conditions. As decreasing the steam/air ratio down to the extreme limit, caused by the fusion point of the ash, increases the chance of channels, it would seem from the rather slight variations in carbon dioxide, carbon monoxide, and hydrogen (and also of methane and hydrocarbons in the gas, variations of which are very small indeed) that it is not necessary to go to the limit of what the

TABLE III—*Variations of Gas Composition with Type of Coal Used*

| Coal | Volatile Matter, % | Tar Content,* grains/cu. ft. | $H_2O$, grains/cu. ft. | $CO_2$, % | CO, % | $H_2$, % | $CH_4$, % | $C_nH_m$, % | Throughput, tons/hr. | Steam/Air Ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| Type *FL* | *ca.* 40 | 9 | 40 | 5 | 26 | 15 | 2·9 | 1·3 | 2·2 | 80 |
| ,, *B* | *ca.* 37 | 7 | 62 | 8 | 22 | 16 | 2·9 | 1·2 | 1·7 | 97 |
| ,, *T* | *ca.* 34 | 6 | 72 | 9 | 19 | 15 | 2·2 | 1·1 | 1·5 | 97 |
| ,, *H* | *ca.* 30 | 5·2 | 80 | 10 | 18 | 14 | 2·1 | 0·6 | 1·2 | 106 |
| ,, *N* | *ca.* 25 | 3·5 | 88 | 11 | 16 | 14 | 1·9 | 0·5 | 1·0 | 110 |

* Assuming fairly well screened coal. With perfect screening, values are about 20% higher

producer crew can do in the way of combating channels. The reason for doing so is, however, again the humidity of the gas and its destructive effect on luminosity of the flame. Care should, however, be taken not to exceed the limit of the accomplishments of the crew.

Changes in throughput also have their influence on the quality of the gas. This appears when the throughput of one producer is changed, as well as when a hand-operated producer is used as stand-by for a battery of large mechanically operated producers. The actual value of the variations in gas quality depends on the properties of the coal, as in our experience usually the coal that gave the best gas showed also the least sensitivity to the fluctuations in throughput. Figure 5 shows some results on two types of coal (both containing about 38% of volatile matter) which differed in fusion point of the ash (*B*, 1250° C.; *FL*, 1350° C.) and in reduction of carbon dioxide and water vapour, but otherwise had nearly the same properties. Whilst the suitability for small throughputs is not much different, coal *B* is far less suited for high throughputs than coal *FL*. Table III summarizes our experiences with different types of coal, showing the large differences encountered.

## The Steam/Air Ratio

Under the conditions mentioned in the introduction, data could easily be obtained on the changes in steam/air ratio to be made when changing over from one type of coal to another. It was found that the departures from a standard condition could be accounted for separately and additively within the accuracy required for normal producer operation. As a standard, a condition was taken that with a good coal (*FL*), a Ruhr coal of volatile matter 39%, ash fusion point of 1370° C., and with 10% of fines (< $\frac{3}{8}$ in.), the gas composition was:

| $CO_2$, % | CO, % | $H_2$, % | $CH_4$, % | $C_nH_m$, % | $N_2$, % | $H_2O$, grains/cu. ft. | Tar, grains/cu. ft. |
|---|---|---|---|---|---|---|---|
| 5·5 | 26·0 | 15·3 | 2·9 | 1·6 | 48·7 | 30 | 9 |

when gasified at a rate of 2·2 tons/hr. with a steam/air ratio of 78, and an air supply of 150,000 cu. ft./hr.

Table IV—*Effect of Variations in Operation on the Steam/Air Ratio*

| | Variation | Difference in Steam/Air Ratio, grains/cu. ft. |
|---|---|---|
| Volatile matter ... | +9 to +11% | −4 |
| Fusion point of ash | +100° C. | −6 to −8 |
| Volume of air ... | +10,000 cu. ft./hr. | +3 |
| $CO/CO_2$ ratio ... | +1 | −2 to −3 |
| Percentage of fine coal ... ... | +10% | +4 |

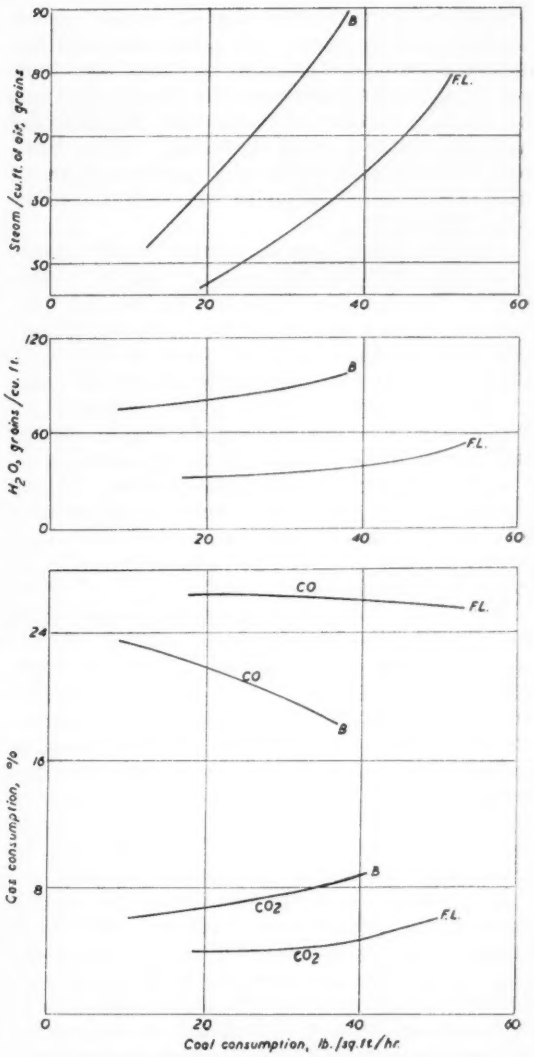



Fig. 5—The effect of throughput on gas quality

The influence of the different factors was determined in part directly, *i.e.*, when coals were used differing in one property only. In most cases it was necessary to plot the steam/air ratio against properties or operating data. The results are set out in Table IV.

The required steam/air ratio was determined in each period, for the same kind of coal, to within ± 2 grains/cu. ft., and within this accuracy the additivity was valid. The humidity of the air was taken into account. As a theoretical check seems as yet impossible, only a few remarks will be made regarding separate factors.

The fusion point of the ash was defined in the usual way, as the temperature in a reducing

atmosphere at which the top of a cone of ash touched the base-plate. On a few occasions the maximum temperatures in the fuel bed were sought by driving thermocouples through fuel and ash bed at a number of places when the producer had just started to show clinkering. It may have been chance or not, but in each case the maximum temperature found coincided well with the fusion point as defined.

Vaporization of volatile matter requires heat, and therefore with increasing volatile-matter content the steam/air ratio can be lowered. An increase of heat absorption by increased decomposition of steam is required, which is about half the heat required for vaporization of the difference in volatile matter. Then clinker troubles are avoided, but a reduction in volatile-matter content still results in an increase in gas temperature of about 40° C. per 10% of volatile matter. As this is detrimental to tar production a slightly greater increase of steam/air ratio is required than that which is necessary to avoid clinker troubles, as given in Table IV.

The volume of air is, within the accuracy of our experiments, linearly correlated with the steam/air. ratio between 80,000 and 170,000 cu. ft./hr. (diameter of producer, 11 ft.). In hand-operated producers nearly the same relation was found, but in a lower range of air volumes. For the same specific throughput the hand-operated producers required about 10 to 15 grains of steam per cu. ft. of air more than the mechanical type, due to the destruction of incipient channels by the levelling device in the mechanical producer.

The ' reactivity ' of the coke formed by vaporization of the volatile matter plays a rôle also in fixing the steam/air ratio. Of course, it is impossible to determine this property in the laboratory, because no adequate sample of the coke can be obtained and because temperature and properties of the coke vary on its way through the producer. The best measure for heat absorbed by the reduction of carbon dioxide and water, would be the reduction of water, which can be determined with fair accuracy. Under the standard conditions about 50% of the steam was reduced, and a variation of this figure by 10% required a change in steam/air ratio of about 4·5 grains/cu. ft. In daily practice, however, this method is somewhat cumbersome as it requires determinations not usually made. It was found then that sufficient accuracy was obtained by correlating the steam/air ratio with the ratio $CO/CO_2$.

The influence of fines on the steam/air ratio could not be investigated satisfactorily as screening facilities were poor. This influence can be attributed only in a small degree usually to the less refractory ash of the fine coal. The major influence seems to be the already discussed inhomogeneity of gas flow, as suspected in a preceding section, which will also increase the danger of channelling. Moreover, when in a dense fuel bed a channel is formed, it is a more dangerous short circuit than in open beds, and therefore it is more necessary to avoid channels in dense beds than in open beds without fines. Disintegration of the coal in the producer has about the same influence as fines in the coal as fed. It has not been possible to give rules for this case.

## Summary

1. Frequent determination of the tar content and humidity in producer gas which is delivered hot to open-hearth furnaces is quite feasible and definitely worth while both for daily control and for investigations of the open-hearth furnace.

2. Tar content was found to vary strongly (between 2 and 10 grains/cu. ft.) and rapidly, although the conditions of gasification seemed fairly constant. The tar content increases rather strongly with increasing volatile-matter content (about 0·4 grains/cu. ft. per 1% of volatile matter), a property of the coal which can vary sufficiently in one consignment to account for variations in tar content of 1 grain/cu. ft. The major effect in our case was, however, that of fines in the coal, which accounted for variations of about 4 grains/cu. ft., *i.e.*, about 0·7 grains/cu. ft. per 10% of fines. Channelling can readily cause variations in tar content of the total gas volume, of 2 grains/cu. ft. The influence of throughput on tar content is rather small (in our case an increase of about 0·2 grains/cu. ft. per decrease of 10,000 cu. ft. of air per hour.).

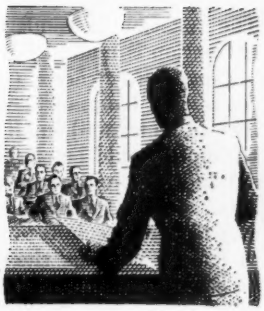
3. The influence of channelling on gas analysis and humidity is shown for channel gas in Table II. The influence of fines in the coal is analogous. Rapid variations of steam/air ratio have a relatively large influence, as is shown in Fig. 4 for an analysis taken 6 min. after abruptly changing the steam/air ratio from 82 grains/cu. ft. to the values shown. Data for changes of steam/air ratio, each time awaiting constant conditions, are also given. Figure 5 shows that changes of throughput have a much stronger influence with mediocre coal than with good coal.

4. Approximate rules are given for changing the steam/air ratio necessary to produce the best quality of gas when the properties of the coal or the throughput are changed.

## Acknowledgment

The writer is indebted to Mr. W. F. Slieker for continuous and ingenious assistance during the investigations.

# DISCUSSION ON PAPERS



DISCUSSION AT MEETINGS · WRITTEN CONTRIBUTIONS

## Spring Meeting, 1947

### Correspondence on the Paper—

### A NEW SCHEME FOR THE MICROCHEMICAL ANALYSIS OF FERROUS ALLOYS*

*By E. J. Vaughan and C. Whalley*

Messrs. **N. Stafford** and **P. F. Wyatt** (Imperial Chemical Industries, Ltd., Dyestuffs Division, Blackley) wrote : This scheme seems to have been admirably worked out, and since the authors are dealing with major or semi-minor proportions of constituents, as distinct from parts per million we think they have pursued the right course in avoiding separations as far as possible, and in depending upon reactions which are highly selective under the given conditions.

Their demonstration that accurate results can be obtained on the Spekker absorptiometer, with cells of considerably smaller capacity than the original design, is also a very useful contribution.

In the first paragraph of column 3, "$H_2S_5$" should be "$H_2S$."

As to the methods in detail, we have the following special comments.

*Molybdenum* (p. 543)—We prefer to extract the thiocyanate complex with an organic solvent, *e.g.*, a 2 : 1 mixture of ethyl ether and petroleum ether, or cyclohexanol.† Not only is the complex more stable than in aqueous solution, but the colour intensity is increased and minor interferences, *e.g.*, from chromium, are much reduced or completely overcome.

*Cobalt* (p. 546)—In our experience, buffering with sodium acetate alone, provides too low a *p*H value for full development of the colour. Also, the precipitate of basic acetates and phosphates of iron, chromium, etc., appears to occlude a small proportion of the cobalt and prevent it from entering into reaction with nitroso-R salt. Further, there is a definite time lag in the formation of the complex, and thus there appears to be a risk that the introduction of nitric acid immediately after the addition of nitroso-R salt and sodium acetate will result in oxidation of the excess of the complex-forming reagent, before all the cobalt has reacted.

*Chromium* (p. 544)—In our experience, different samples of diphenylcarbazide, *e.g.*, samples obtained from different sources, give widely different optical-density values for the same amount of chromium, and we regard it as essential that a fresh calibration curve be established with each new batch of reagent.

*Copper* (p. 548)—Here we would prefer to extract the copper diethyldithiocarbamate complex with an organic solvent, *e.g.*, carbon tetrachloride or chloroform, so that it is obtained in true solution rather than as a colloidal dispersion. In this way a higher level of optical density is obtained and Beer's law is more closely obeyed.

---

* For Discussion see *Journal of the Iron and Steel Institute*, 1947, vol. 156, Aug., pp. 487–491.

†E. B. Sandell, "Colourimetric Determination of Traces of Metals," pp. 331–332. New York, 1944: Interscience Publishers.

The reaction is rendered more selective if the extraction is made from an *acidified* solution.*

*Composite Scheme* (p. 558)—In the sulphide separation (column 3) we would have thought it inevitable that (i) small amounts of tungsten and titanium would be carried down with the copper sulphide precipitate, particularly as no complexing agent such as tartaric acid is used to prevent this, and (ii) the precipitation of such a small amount of copper without the aid of a ' carrier ' would be not quite complete. Since separation of copper only, is required, a safer course would appear to be a solvent extraction, *e.g.*, with diethylammonium diethyldithiocarbamate in chloroform, from the acid ($H_2SO_4$–$H_3PO_4$) solution (*see* reference above, under ' Copper '). So far as we know, neither tungsten, titanium, nickel nor chromium will be extracted under these conditions.

Mr. **R. C. Chirnside** (Research Laboratories, General Electric Company, Ltd., Wembley) wrote: Mr. Vaughan and Mr. Whalley are to be congratulated on having taken their pioneer work on the applications of the Spekker absorptiometer to yet a further stage of development. The methods which Mr. Vaughan set out in his lectures to the Royal Institute of Chemistry in 1941 and 1942, undoubtedly began a revolutionary era in metallurgical analysis, and this record of his more recent work consolidates and establishes these new techniques.

The discovery by the authors (p. 537), that only a very small proportion of the cell in the Spekker instrument is effectively used for absorptiometric, purposes, is important, and the designing of micro-cells so as to increase the sensitivity of the instrument without having to modify the chemical conditions of the method, was undoubtedly sound. One wonders if the instrument makers have any alternative scheme to offer.

The section on the preparation of the sample, on p. 538, is very useful, and this part of the analytical process is often not sufficiently appreciated by those for whom the analysis is required.

For purposes other than routine control analysis, the use of corrections, of which that described under the method for chromium (p. 545, in which a correction of 0·10% for each 5% of nickel is applied) is not attractive. The average deviation from the mean figure when determining a major constituent is also, in some instances, greater than would be tolerated in other methods; however, these disadvantages have to be offset against the obvious advantage of being able to carry out a complete analysis on as little as 15 mg. of material. With an improvement in filter characteristics, considerable increases in sensitivity may yet be possible.

The method for the determination of iron in ferrous alloys seems least satisfactory. Presumably, to extend the range beyond 6% would result in an average deviation from the mean figure which would be so large as to be unacceptable. One feels that a method for the accurate determination of iron when it is present in proportions of approximately 50% of the alloy, and more particularly in the presence of elements such as cobalt, nickel, and chromium, is urgently required.

The method for the determination of sulphur using an indirect absorptiometric finish is particularly ingenious, and suggests that similar methods may eventually find their place in the determination of some other elements.

One would have liked to see the word " boron " occurring in the list of less-common elements on p. 556, for which methods have been devised.

## AUTHORS' REPLY

Messrs. **E. J. Vaughan** and **C. Whalley,** in a joint reply to the discussion and the correspondence, wrote: The authors wish to thank all those who have taken part in the discussion for their very kind and encouraging remarks.

The value of the method for the determination of iron has been raised by more than one speaker and it appears that considerable confusion has been caused by the printer's error on Fig. 20 (*a*). The range of iron concentration should be in milligrams and not in percentages. This means that the range covered in a 3-cm. cell is from 0 to 100% of iron. As stated in the text this method was put in purely to check the analysis of complex alloys, and should the determination of iron in smaller amounts be necessary, good alternative methods are available.

The reasons for the preferred alternative extraction methods of Messrs. N. Strafford and P. F. Wyatt in the case of molybdenum and copper are fully appreciated. It was, however, one of the aims of the work described in the paper, to cut down chemical procedure to a minimum, subject, of course, to the achievement of a satisfactory accuracy of determination.

The sulphide separation of copper appears to be almost quantitative, as the sulphur precipitated acts as a collector. When titanium and tungsten are present small quantities of these elements are carried down with the copper and consequently, as stated in the text, the determination of these elements is not quite so accurate following a sulphur separation, but is still good, as shown by the results obtained.

Regarding the alternative procedure of using compensating solutions instead of a straight-

*N. Strafford, P. F. Wyatt, and F. G. Kershaw, *Analyst*, 1945, vol. 70, p. 232.

forward absorption measurement, this is open to criticism. This technique was fully investigated and it was found preferable to measure the blank as a sample of pure iron containing all the reagents including a complex-forming reagent and apply small corrections. In many cases use of a compensating solution would not suffice, as the interference of other elements is caused by their reaction with the complex-forming reagent and only appears upon its addition.

In considering the possible effects of the application of this method to 80-ton ingots it is observed that no single macro sample would be expected to give a true picture of the composition of such an ingot. The micro sample would give a picture even further removed from the truth. On the other hand, if a study of segregation in such an ingot is desired, the micro sample is capable of giving more reliable information than the macro sample. It has already been stated that the micro methods were developed for a special purpose, and uses to which they can be put have been given. The authors will be only too pleased to know that other workers can use these methods, either in their present form or suitably modified, on their own particular problems.

The authors would draw to the attention of readers that the third sentence of the last paragraph in the first column on page 490 of the August *Journal* should read, " If you have a 50-mg. sample of steel and it contains 0·1% of carbon, you get only about 0·17 mg. of carbon dioxide, and 0·17 mg. is not very much to weigh even on an accurate microbalance."

## Correspondence on the Paper— GRAPHITE FORMATION IN CAST IRON AND IN NICKEL–CARBON AND COBALT–CARBON ALLOYS*

*By H. Morrogh and W. J. Williams*

Mr. **B. H. Alexander** and Mr. **C. A. Dubé** (Department of Metallurgy, Carnegie Institute of Technology, Pittsburgh, Pennsylvania) wrote: The mechanism of freezing and the morphology of the solidification products in alloy systems have always been of great importance to metallurgists, and much attention has been devoted, rather unsuccessfully, to studies of the related problems. Not the least perplexing of these problems is that of " modification "†; the authors' exhaustive treatment has accomplished much towards a final solution of this problem. The experimental work is of a very high character, and its publication will be gratifying to all workers in the field. The authors have also demonstrated that in the realm of the unknown, theories abound. The present writers will attempt in the following to add what they can to the great value of this paper.

The concept of labile and metastable regions in binary systems became widely known through the work of Miers, but this concept has since come to be regarded as a mere convenience with no physical significance. De Coppet,[1] in 1875, first voiced objection to the idea of a " metastable limit," and, after considerable argument with Ostwald and other chemists of the time, he showed[2] by experiments extended over several years that no region exists below the solubility curve where spontaneous nucleation does not occur. His work has since been confirmed by many investigators, most notably by Othmer[3] and Young.[4] Modern theorists in phase transformations also have come to agreement that the " metastable limit " merely represents a stage, in principal somewhat ill-defined, at which the probability of crystallization increases rapidly,[5, 6] occurring during the period of observation (which is rarely very extended).

Thus, it would appear to be unwise to found a theory of modification on such a concept. Moreover, the treatment of the solidification of alloys on the basis of " supersolubility curves " as given by Desch and quoted in the paper goes outside the limits of such a theory, even if it were correct. That is, when a nucleus is formed after undercooling to the " supersolubility curve " and the solid phase begins to appear and grow, it cannot be assumed that the liquid approaching equilibrium with this solid will have a composition which is represented by the " supersolubility curve." This " supersolubility curve " has no thermodynamic significance and cannot represent equilibrium concentrations during a phase transformation. It is an imaginary region which represents the extent of undercooling at which the rate of nucleation becomes very large. Furthermore, the authors' observations as well as those of Boyles to which the authors refer concerning the eutectic cell size seem to refute the idea that the modified structure arises from solidification

* For Discussion see *Journal of the Iron and Steel Institute*, 1947, vol. 156, Aug., pp. 491–496.

† The term " modification " has never been given a strict definition. Most commonly, it is used to describe the process of the refining and alteration of the structure of a binary eutectic alloy.

at a " hypereutectic point " (*i.e.*, the intersection of two " supersolubility lines "). They found that the eutectic cell size was always coarser in the modified alloys, yet solidification on a " supersolubility curve " or a " hypereutectic point " has been shown by Miers and Isaac to give rise to a " shower " of nuclei, and consequently a very fine cell size would be expected in the modified eutectic if this were the case.

It is interesting that the authors have come to the conclusion that the eutectic is probably inoculated by graphite, inasmuch as Patterson,[7] in a thermal study of several eutectic systems, found that the eutectic was not inoculated so well by the higher melting component in a binary system as by the lower melting component. He found that in the aluminium–silicon system the deposition of primary silicon did not nucleate the eutectic as readily as the deposition of the lower-melting aluminium as the primary phase.

The authors have pointed out several analogies that exist in systems of the betol-salol type, such as iron– cobalt– and nickel–carbon, and aluminium–silicon. Work in progress in the Metals Research Laboratory at the Carnegie Institute of Technology has shown that the silver–silicon, and probably also the gold–silicon, systems behave similarly with respect to modification. Other systems, such as mercury–zinc, water/potassium-nitrate, and benzene–toluene have been shown to have similar characteristics.[8] These systems, at least the metallic ones, are composed of two components having greatly different melting points. The lower-melting element in each metallic system has a closer-packed crystalline structure than the corresponding high-melting component. It has been shown by work done at the Carnegie Institute of Technology and elsewhere[9] that the tendency for an element to undercool is closely related to its crystal structure. The elements with close-packed structures such as lead, aluminium, copper, etc., cannot, under similar conditions, be undercooled as readily as the elements with a more complex structure. Furthermore, the elements of the latter group, such as silicon, antimony, bismuth, etc., have a much lower characteristic velocity of crystallization than the former. It is evident how some of these considerations may be related to the problems of modification.[10]

The possibility suggested by the authors that modification of the eutectic in these systems may be associated with the decomposition of a metastable compound is very interesting and, as they say, it should receive further consideration. However, the writers are in disagreement with their references to " supersolubility curves " in explaining possible mechanisms of freezing.

We suggest the following mechanism as a simpler and more possible explanation of the origin of the modified structures in such systems. This theory is an extension of the ideas already published on the problem of modification,[10, 13] and is based on the familiar concept of extrapolated solubility lines which has proved successful in the elucidation of many phenomena pertinent to the decomposition of austenite in iron–carbon alloys. An alloy of composition *X* (*see* Fig. A, which represents a schematic diagram of the type of system susceptible to modification) is cooled rapidly, and at some point below the solubility line of β (*B′B″*) this phase is precipitated. The liquid at the interface of this phase will automatically assume a composition which closely approaches the line *B′B″*. Now, as we stated before, the rate of growth of the β phase in these systems which are susceptible to modification is characteristically smaller than that of the α phase. This has been shown to be related to the complex crystal structure of component *B*, and may also be influenced by alloying elements. Because of this small rate of growth, the system as a whole will, during cooling, depart considerably from equilibrium, except in the immediate neighbourhood of the interface. Thus, the liquid at this interface will approach the composition *e* when the eutectic temperature, *Te*, is attained. The α phase can only be precipitated from this moment on, and initially only at the interface. The rate of growth of α is very large as compared to β, thereby accounting for its surrounding the primary β particles. Primary β may still be nucleated and grow in other regions of the liquid

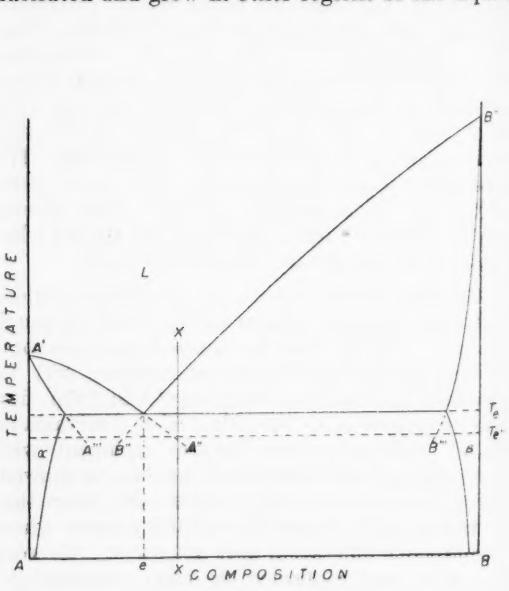



FIG. A—Equilibrium diagram of alloy system susceptible to modification treatment

phase. As a result we have the "independent" precipitation of both α and β. If we allow the reaction to proceed at this temperature, a divorced eutectic will result, for which we have much experimental evidence. The type of eutectic structure obtained in a binary system is clearly a function of the relative rates of nucleation and growth of the two phases. Furthermore, these rates of nucleation and growth may vary differently with the degree of supersaturation. Near the eutectic temperature in this case, the large rate of growth of the α phase rapidly relieves the supersaturation of the liquid phase with respect to element *A*. The characteristic small rate of nucleation and growth of element *B* will be responsible for the overall low rate of reaction at the eutectic temperature, *Te*. The rapid removal of heat which we have postulated will result in a lowering of the temperature of the system. As the temperature is lowered, the morphology of eutectic precipitation described above, namely the independent growth of the two primary phases, will be maintained as long as the rates of nucleation and growth of the two phases are widely different. The composition of the α and β phases precipitated at these lower temperatures will approach the extrapolated lines *A'A'''*, and *B'B'''* respectively, while the composition of the adjoining liquid phases will approach the lines *A'A''* and *B'B''*, respectively. The supersaturated solid phases would be expected to precipitate their excess solute and in this way the occurrence of the Widmanstätten carbides in the "*A*" phase (Figs. 87–89) which the authors obtained by very rapid quenching of a nickel–carbon alloy is explained. Peshkov[8] actually observed under the microscope the decomposition of the solid phases in modified eutectics in the $H_2O$–$KNO_3$ system, which is transparent. The retarding effect of the slower rate of crystallization of the β phase contributes to the further supersaturation of the system. A lower temperature, *T'e*[1], is finally reached where the characteristic rate of nucleation and growth, *i.e.*, the rate of deposition, of the β phase becomes very large, at least comparable to that of the α phase. At this temperature the rate of reaction will be very fast, and because of its exothermic nature the temperature of the system will be maintained approximately constant—it will give the appearance of an eutectic arrest upon thermal analysis. In this way a modified eutectic will be obtained because it has formed at a lower temperature where the eutectic is characteristically finer. The addition of alloying elements, which may affect the thermodynamic nature of the system or the kinetic factors controlling the reaction, may have profound influence on the nature of the reaction, as the authors have demonstrated. The complex nature of the influence of alloying elements is such that theory in its present state cannot predict the specific effect of any of them. This same argument can obviously be applied to compositions in the system other than composition *X*, Fig. A.

The best-known case in which a similar type of problem has been investigated is the study of the rate of decomposition of austenite as a function of temperature. This eutectoid reaction exhibits peculiarities which are very similar to those found in the case of so-called modified alloys. For example, the $Ar_1$ line of the early investigators of the iron–carbon alloys follows a course which is entirely similar to the one observed by Gwyer and Phillips[10] in the modified aluminium–silicon alloys. The change in eutectic composition has been observed in both systems. Recently, microstructures have been published[11] which clearly show divorcement of pearlite in certain types of alloy steels. In pure iron–carbon alloys of eutectoid composition, divorcement of pearlite occurs readily if the transformation is allowed to proceed very near the eutectoid temperature.[12]

Superheating, which, as is well known, decreases the rate of nucleation, would promote undercooling and aid the occurrence of modified structures by the mechanism outlined above. The effect of addition agents, including gases, might be expected to be widely different, depending upon their effects on the rates of nucleation and growth of both *A* and *B*. This theory would predict that the eutectic temperature of modified alloys would vary with rate of cooling and also with composition as had been found by many workers.

### *References*


1. M. C. DE COPPET, *Annales de Chemie et de Physique*, 1875, vol. 276, pp. 275–288.
2. M. C. DE COPPET, *Ibid.*, 1907, vol. 370, pp. 457–527.
3. P. OTHMER, *Zeitschrift für anorganische Chemie*, 1915, vol. 91, pp. 209–247.
4. S. W. YOUNG, *Journal of the American Chemical Society*, 1911, vol. 33, pp. 148–162.
5. C. N. HINSHELWOOD and H. HARTLEY, *Philosophical Magazine*, 1922, vol. 43, pp. 78–94.
6. M. VOLMER, "Kinetik der Phasenbildung," Dresden, 1939 : Theodor Steinkoff.
7. W. PATTERSON, *Giesserei*, 1939, vol. 26, pp. 461–466.
8. B. PESHKOV, *Acta Physicochimica*, 1946, vol. 21, pp. 109–134.
9. V. DANILOV and W. NEWMARK, *Physikalische Zeitschrift der Sowjetunion*, 1937, vol. 12, pp. 313–323.
10. A. G. C. GWYER and H. W. L. PHILLIPS, *Journal of the Institute of Metals*, 1926, vol. 36, p. 283.
11. R. A. GRANGE, *Transactions of the American Society for Metals*, 1947, vol. 38, p. 879.
12. R. F. MEHL, *Ibid.*, 1941, vol. 29, pp. 813–861.
13. J. D. EDWARDS, F. C. FRARY, and Z. JEFFRIES, "The Aluminium Industry," p. 72. New York, 1930 : McGraw Hill Book Co., Inc.

## AUTHOR'S REPLY

Mr. **H. Morrogh** wrote in reply : The authors are indebted to Mr. Alexander and Mr. Dubé for their contribution to the discussion and for the interesting theory which they have put forward.

The limitations of the concept of undercooling implicit in the work of Miers were appreciated by the authors, and one of the facts emerging from this work was that this concept could not be applied to iron–carbon–silicon, nickel–carbon, and cobalt–carbon alloys. The alternative explanation put forward, however, appears completely to ignore one fact of experimental observation, which in the opinion of the authors has now been amply confirmed, namely, that the " modified " structures in the iron–silicon–carbon, the nickel–carbon, and also probably cobalt–carbon alloys, form by the solidification of a binary complex, one phase of which is a metastable compound which decomposes after solidification. The finely divided " modified " structure, whilst having the appearance of a " modified " eutectic, is in fact the result of a reaction occurring in the solid state. If the theory put forward by Mr. Alexander and Mr. Dubé fits the experimentally observed facts for the systems they have quoted, without the recognition of a metastable phase, then clearly we must look for a further explanation for the process of undercooling in the systems mentioned above. Perhaps undercooling can occur by more than one process.

The term " nucleus " has been very loosely used in the literature, and the present authors are probably not without reproach in this respect. Speaking broadly, however, they would confine the meaning of the term to that physical condition permitting crystallization of a given phase to begin at a given instant in time. This physical condition may result from the presence of a small solid particle, a phase interface, a lattice imperfection, or a state of strain, the last three being essentially very similar. In referring to the work of Miers and Isaac, the contributors to this discussion refer to a " shower " of nuclei, and here the term refers only to the actual visible growing crystals. In this connection considerable confusion may arise when dealing with eutectics—in this case we have to deal with the initiation of crystallization of at least two phases. The number of centres at which this multi-phase crystallization begins may be few, leading to a large eutectic cell size, but at the same time the particle size of the phases of the complex may be relatively fine.

In the case of the iron–carbon–silicon alloys it would appear that in the liquid the carbon is very intimately connected to the iron—one hesitates to claim as iron carbide. For the austenite–graphite binary complex to form, some " nuclei " are necessary to encourage the dissociation of this bond. If these " nuclei " are not present, then solidification of the binary complex takes place to give austenite and iron carbide. It is possible that time is required to allow these " nuclei " to effect dissociation, and so relatively rapid cooling, even in the presence of " nuclei," causes the austenite–iron carbide complex to solidify. Immediately after solidification the carbide phase of this complex decomposes *in situ* to give austenite and graphite. This latter reaction could be " non-nuclear," but there is some evidence to suggest that it occurs at a number of points from which it spreads on a corresponding number of spheroidal reaction fronts. This carbide decomposition does not appear to be accompanied by any appreciable diffusion of carbon, for instance, in austenite, and this is the implication of saying that it occurs *in situ*.

It can be argued that the carbidic binary complex must also have its crystallization initiated by " nuclei," but, this granted, there is no reason why they should be the same in type or number as those necessary for the solidification of the austenite–graphite binary complex. If they are fewer, then this would account for the larger binary complex cell size in irons which have undercooled structures. It must, however, be emphasized that the fine particle size of the graphite in undercooled cast irons is in no direct way related to the nucleation conditions before or after solidification, but to the peculiar conditions operating after solidification during the decomposition of solid iron carbide. The primary effect of the " nuclei " is to determine whether or not the alloy will solidify with a graphitic binary complex.

Mr. Alexander and Mr. Dubé refer to the probable influence of crystal structure of the solid phases upon ability to undercool. This arouses an interesting train of thought, but the iron–silicon–carbon, the nickel–carbon, and the cobalt–carbon alloys not only contain graphite which can be said, compared with most simple metallic phases, to have a relatively complex crystal structure, but they also have carbide phases which, whilst having relatively complex crystal structures, also have the important property of metastability. It is felt that in this context the metastability of the carbide phases is at least as important as the crystal-structure considerations.

An attempt to study phenomena such as undercooling in systems widely differing in type is justifiable, but many pitfalls are possible. In comparing the iron–silicon–carbon, the nickel–carbon, and the cobalt–carbon systems, we are on fairly safe ground by virtue of the position of

the elements iron, cobalt, and nickel in the table of elements. In addition, all these elements form similar metastable carbides. When, however, an attempt is made to cover a wider field, to include, for instance, the systems aluminium–silicon, silver–silicon, gold–silicon, mercury–zinc, etc., one is justified in asking whether they also are capable of solidifying with a metastable phase which can decompose after solidification. Some systems having a peritectic and a eutectic transformation show undercooling past the peritectic transformation, with the formation of a metastable eutectic, and reference has been made to these in the paper. Is there any evidence, however, for the occurrence of a metastable aluminium–silicon compound? If there is not, then we must postulate at least two different types of undercooling in eutectic structures—one for alloys of the aluminium–silicon type, and one for alloys of the iron–silicon–carbon type having a metastable phase.

## Correspondence on the Paper—

# A PHOTOGRAPHIC INVESTIGATION OF THE BRIGHTNESS TEMPERATURES OF LIQUID STEEL STREAMS*

*By J. A. Hall*

Mr. **W. J. Todd** (Messrs. Hadfields, Ltd., Sheffield) wrote : These investigations must really be considered and linked up with previous work on the deterioration of ' quick immersion ' thermocouples carried out by members of the original Sub-Committee. This is given in the Second and Third Reports of the Liquid Steel Temperature Sub-Committee published in 1939 and 1942 respectively.††

Contamination may result in brittleness and change in calibration in varying degree, *i.e.*, both physical and thermo-electric properties may be affected. The present series of investigations afford a completely satisfactory explanation. The previous work considered the accuracy of temperature measurement as affected by change in thermo-electric properties. Obviously this is as important as freedom from breakage, possibly more so, since on occasions no determination at all might be better than a false one.

It was then found that a couple could be immersed upwards of 20 times before its accuracy fell off by more than 5° C. These tests were made before the graphite end block came into use, so that for present-day practice, the accurate life may be much less on the average. However, if the recommended procedure of cutting back the hot junction after about every six immersions is carried out, good working accuracy can be relied on.

From the more recent investigations it may be inferred that calibration is not affected by embrittlement, or that no relationship exists between the two properties, physical and thermo-electric. My extended experience appears to confirm this, but the matter is most complex. Thermocouples may be badly contaminated and be a matter of 100° (C.) low in calibration without showing embrittlement, but only on rare occasions do they exhibit embrittlement without also suffering in calibration. (This statement refers to pyrometry generally, including heat-treatment applications as well as quick-immersion technique.)

As regards quick-immersion pyrometry, we at Hadfields have been remarkably trouble-free as regards breakages, and we have had no bad periods, which we attribute to our practice of ' burning off ' the components before use, as recommended by Dr. Schofield. I recall that when I joined the organization in 1911, it was their established practice to subject the clay couple insulators, as received from the manufacturers, to this ' burning off ' process before putting them into use. This precaution is still carried out.

The use of a metal-tube-protected thermocouple without an inner refractory protection sheath was condemned by all pyrometer manufacturers; nevertheless, for certain of our heat treatment processes it was a risk that had to be taken, but with adequate supervision and maintenance we got away with it. Some 15 years ago we introduced our own Ni–Cr tubing, to replace mild steel tubing in use up to that time. After being repeatedly heated and cooled each day in the 800°–900° C. range, thermocouples showed remarkable maintenance in calibration; the

* For Discussion see *Journal of the Iron and Steel Institute*, 1947, vol. 156, Aug., pp. 497–500.

† Second Report of the Liquid Steel Temperature Sub-Committe, *Iron and Steel Institute Special Report No. 25*, 1939, pp. 235–264.

‡ Third Report of the Liquid Steel Temperature Sub-Committee, *Journal of the Iron and Steel Institute*, 1942, No. I, pp. 213–243 P.

departure was negligible even after a year's working.

In this practice, however, we struck bad periods, when couples became contaminated (*i.e.*, their calibration was affected though they did not always become embrittled) sometimes after a single initial heating. Quite extensive investigations were made, from which it was concluded that the seat of the trouble was in a particular batch of tubing. Various ' rectification ' treatments were tried out, and the most effective proved to be soaking at 1000° C. for a period extending to 80 hr. or more with the tubing in a vertical position. (Passing air or oxygen through the tube was of no particular benefit.) After such treatment the tubing proves to be quite satisfactory.

No clear understanding of the cause of this contamination could be arrived at from our investigations ; but we concluded that it was bound up in a carburized skin existing on particular tubing (the result of the lubricant used in the process of manufacture) coupled with selective diffusion occurring when heated.

No doubt this contamination is allied to the embrittlement effect which has been so successfully explained in the series of papers presented in this Symposium, and I will offer my sincere thanks to the authors for the satisfaction of understanding fully the mechanism of the process of this effect on calibration.

Mr. **D. Knowles** (Messrs. Hadfields, Ltd., Sheffield) wrote : I should like to congratulate Mr. Hall on the able manner in which he has sorted out the pertinent factors from the data obtained during these investigations. We have here another full and careful investigation which we always associate with the work of the National Physical Laboratory.

Mr. Hall has thrown some light on a number of factors which have been somewhat puzzling to the observers using optical pyrometers under works conditions. He has shown that what appears to the observer as a zone of clear metal, actually contains numerous bright areas of higher emissivity than the background, which are moving too rapidly for the human eye to discern them. It is interesting to note that Burgess, in his monumental work as long ago as 1917, found that under laboratory conditions molten steel had an emissivity factor of 0·37 but that under melting-shop conditions a factor of 0·40 was nearer the mark. Mr. Hall, I believe, has found an explanation of why the higher factor was found necessary under works conditions.

There appears to be a prevalent opinion that using a disappearing-filament pyrometer for molten-steel temperature measurements consists of simply sighting down a telescope and matching an illuminated lamp filament against a bright background. In addition to the obvious factors of ensuring that the instrument is correctly focused and in good working order, there are the ever varying conditions of prevailing atmosphere, metal surface, and metallurgical factors which must be taken into consideration. To anyone interested in the work it becomes second nature to be critically observant of the melting conditions in the furnace and of the bath. The manner in which the furnace is tapped and the behaviour of the ladle man, are also factors which have a bearing on the reliability of the optical reading, and require considerable experience before their influence can be assessed. Above all, the observer must be conscientious, for it is only by such means that real research progress can be made. It must be admitted, as Mr. Barber has shown in his paper,* that the present optical pyrometers are not of the desirable standard and any improvements in this direction will be tremendously appreciated.

We commenced using the disappearing-filament optical pyrometer for observing the brightness temperature of molten steel, in the early 1920's, chiefly as a control instrument rather than as an accurate measurer of true temperature. In fact, it quickly became apparent that the recognized emissivity factor of 0·4, then used for correcting the brightness temperature to true temperature, did not always apply, particularly in the case of alloy steels. However, for control purposes this disability was not of serious consequence and, having once established the optimum conditions required for a particular steel, control was possible. With the introduction of immersion couples, the technique at the furnace has been modified somewhat, but there are still conditions where the portability, speed, and ease of manipulation of the optical pyrometer are decided assets under works conditions, particularly in the casting pit and the foundry, where speed of observation and accessibility to the casting stream are important.

According to Mr. Hall's investigations, the tendency for optical pyrometers to read high, on rapidly moving streams, is due to rapidly moving bright areas chiefly caused by the surface configuration of the stream and reflection. It occurs to me that probably a few stereoscopic stills should verify that fact. Furthermore, the same idea could probably be adopted in the works for record purposes. Such stills will show some area of clear metal normal to the line of sighting, and the four strip-lamp images could afterwards be recorded on a selected area of the plate before

* C. R. Barber, *Journal of the Iron and Steel Institute*, 1945, No. 2, pp. 171–188 P.

development, and used for calibration purposes. I don't suppose the accuracy of the derived temperature will be of the same order as that depicted in Mr. Hall's paper, but an analysis of the accumulated data may be of great interest from the metallurgical aspect. I have often been intrigued by the refusal to continue casting certain heats which, according to the optical pyrometer, are 40° or 50° C. hotter than the same type of steel which under similar conditions has been cast right out. Of course, there is the usual comment that it is fluidity and not temperature that matters in the foundry, which points out that there is some connection between fluidity and emissivity.

Mr. Hall refers to two causes of bright patches in the metal stream, slag and surface folds. I think there is a possible third factor, but how far it occurs in swiftly moving streams I cannot say. I am thinking of the thin oxide film which speedily forms on the surface of molten steel, which Mr. Hall may intend should be included in his term "slag." This oxide film is distinct from furnace slag, and its nature varies according to temperature and composition of the metal. With plain carbon steels, the movement of the stream may be sufficient to break the film as rapidly as it is formed, but the same may not apply to high alloy steels.

The shots of the splayed stream, such as that shown in Fig. 26 (*b*), were of considerable interest. It had been noticed that although such streams may occasionally give low readings, in general they give high readings, and until we saw the cinematograph films depicting the excessive folding which occurs in such streams, we were lacking for an explanation. It is somewhat intriguing to find that one reflection in a fold is sufficient to raise the emissivity of the metal from approximately 0·40 to that of slag, 0·65. Under such conditions it is not surprising that observers may fall into the error assuming all such bright spots to be slag.

There may be a criticism raised as regards the location of the chosen spot in the selected frame. The general technique was as follows. After processing, the film was projected at normal speed to give the general picture of the stream, and then the frames in the vicinity of the "*now*" frame were examined in detail and the one selected which gave the closest agreement to the general picture.

Finally, now that a technique has been established for the photographic determination of the brightness temperature of liquid steel, the question arises of the practical significance in steel manufacture and the quality of its products which, after all, is of fundamental importance. The test of academic research lies finally on its practical application, and it will be with great interest that we await the publication of Mr. Hall's further work in connection with this problem of the measurement of the temperature of molten steel.

Dr. **Schofield** (Freshwater, Isle of Wight) wrote: Mr. Hall is to be congratulated on having achieved a photographic method of measuring brightness, which not only approaches the optical pyrometer in precision, but affords the unique advantage of an instantaneous record of temperature distribution over a wide field of view. This method will no doubt, as anticipated, open up a field for the precise determination of emissivities which, it is hoped, will cover the visible spectrum. In the present paper, the radiation conditions of the steel stream, and the limitations of the disappearing-filament pyrometer have been submitted to an analysis which, in the latter case at any rate, is so searching as apparently to leave little scope for further investigation. The author's finding that, even with skilled observation, the uncertainties in the *apparent* temperature given by the pyrometer may be of the order of ± 20° C., seems to hold out little prospect of the instrument being used generally for purposes of control, since to obtain the *true* from the *apparent* temperature, any uncertainty due to the varying emissivities of steels must be added. These, as the recently published work of Knowles and Sarjant* indicates, are considerable. In fact, the main hope of overcoming the difficulty would seem to lie in the possibility of being able to classify steels according to their emissivity values, and in the case of specially selective varieties, of specifying the waveband suitable for observation.

The uncertainties attached to the brightness pyrometry of steel streams suggest an inquiry into the feasibility of employing the colour, instead of the brightness, principle. When this idea was put forward some years ago from a German source, Todd† found that the claims made were unsubstantiated, and the instrument recommended was unsatisfactory. Nevertheless the method is essentially sound provided that certain conditions are fulfilled. Ideally, the steel should be neutral, *i.e.*, show a constant emissivity throughout the spectrum, as should also be any disturbing factors such as smoke, fumes, or oxide skin. The author has established that the most common cause of bright patches on a steel stream is superposed reflection due to concavity, a single such reflection being capable of giving a rise in brightness temperature of some 60° C. Colour temperature, depending as it does only on the *proportions* of the energy radiated in the several wavelengths, would be unaffected by single or

* D. Knowles and R. J. Sarjant, *Journal of the Iron and Steel Institute*, 1947, vol. 155, April, p. 577.

† W. J. Todd, *Metal Treatment*, 1939, Autumn, vol. 5, pp. 171–174 and p. 184.

multiple reflections of the neutral steel or by the other neutral agents, and would in fact be identical with the true temperature. Moreover, under the conditions indicated, large areas of the stream could be used without the necessity of careful selection as in the case of a brightness determination. This last-mentioned feature would be of particular advantage for a colour pyrometer worked by means of photocell. The writer, with Mr. Hitchman, has done a considerable amount of work on colour pyrometers, operated both by eye and by photocell, and can testify as to the difficulty of evolving a type suitable for steelworks. He would suggest that, before any scheme of colour pyrometry is attempted, there would be great advantage in obtaining data as to the spectral emissivities of a selection of steels. For a start, a close sub-division of the spectrum would be unnecessary, and two filters, in addition to the red already used, would probably suffice. The possession of the data suggested should enable an estimate to be formed of the possible advantages of the colour over the brightness principle in the pyrometry of steel streams.

## AUTHOR'S REPLY

Mr. **J. A. Hall,** in reply, wrote : Further consideration of Dr. Main's suggestion as to the analysis of the frequency curve of Fig. 61, makes me feel that his interpretation is almost certainly right, but the presence of the large centre peak shows that the size of the scanning spot is large compared with that of any areas of even tone in the negative. Clearly, if one used a large scanning spot, covering the whole image at once, a single reading corresponding to the centre peak would be obtained, and the fact that this centre peak in Fig. 61 is so much higher than the two which are really significant, shows that this limiting case is being approached.

Dr. Main raises the point as to whether the peak in Fig. 52 at 1505° C. might be caused by slag. In so far as its brightness is concerned, this might well be so, but the general configuration of the stream suggests that the black-body enclosure effect is the real cause.

As regards Fig. 58, I have now consulted my records of this heat, and find that owing to a camera failure only one other shot was taken. This was exposed 1 min. later, and during a run of 1·3 sec. the mean photographic brightness temperature rose from 1380° to 1440° C. Clearly, owing to the meagreness of the stream, a steady temperature had still not been attained, so no reliance can be placed on these values for an emissivity calculation. The value of 1440° C. would yield an emissivity value of 0·34.

I agree with Mr. Knowles that the question of a thin oxide film, as distinct from slag or refractory contamination of the metal surface needs investigation, and to that end we are trying to to obtain some direct emissivity values by comparing the brightness of a metal surface under an inert atmosphere with that of a small black-body enclosure immersed in the metal. If this yields a value appreciably lower than the lowest obtained in technical practice, it will be strong evidence that surface oxidation is appreciable. So far however, no results are available.

As Dr. Schofield points out, the use of colour temperature measurement is attractive as a means of avoiding some of the sources of error which have been brought to light in the present paper, and the need for an investigation into the spectral distribution of the radiation from different steels has not been overlooked. Dr. Schofield suggests that, as a preliminary, the use of three colour filters would suffice, but my experience with the direct-vision grating spectrograph used for the determination of the effective wavelength in the present work, convinced me that it would not be difficult to build a portable wedge spectrograph which could be used either in the laboratory or in the works, and which would give a complete plot of the energy distribution at all wavelengths shorter than about 0·66, to an accuracy at least comparable with that attainable by the methods used in the present work. It is hoped to proceed with work on these lines. There is, however, the point to be considered that, whilst colour-temperature observation might be a better method of arriving at the true temperature of the metal, it might still be desirable to measure the brightness temperature as well in order to obtain a value of the emissivity if there should turn out to be, as Mr. Knowles suggests, a correlation between emissivity and other important physical characteristics of the steel.

## Correspondence on the Papers—

# THE OPERATION OF OPEN-HEARTH FURNACES WITH COKE-OVEN GAS* *by D. Kilby*

## and—AN EXPERIMENTAL FURNACE FOR THE INVESTIGATION OF OPEN-HEARTH FURNACE COMBUSTION PROBLEMS*

*By A. H. Leckie, J. F. Allen, G. Fenton, J. R. Hall, and C. Cartlidge*

Ir. **J. E. de Graaf** (Koninklijke Nederlandische, Hoogovens En Staalfabriken, N.V., Ijmuiden, Holland) wrote : May I express my high appreciation of the important work done by Dr. Leckie and his colleagues, as the intelligent use of a small-scale experimental furnace will certainly yield information not easily obtained in actual meltingshop practice. This is definitely proved by the papers.

One disadvantage, however, seems to be that essential and theoretical points of interest cannot be investigated, in the rather complex set-up of a complete furnace, as clearly as in special apparatus designed exclusively for the essential investigations of mixing and burning. It is the necessity for work of this kind, alongside work of more direct practical interest, such as that of Dr. Leckie and his colleagues, which I stress. The work of Rummel was done ten years ago, and it seems that since then very little advance has been made into details of mixing and burning which could, if sufficient knowledge were available, decrease the necessary amount of semi-technical work whilst at the same time making it more generally applicable.

It is commonly accepted that under the conditions of the open-hearth furnace, the rate of burning is determined by the rate of mixing. This rate of mixing depends on turbulence, as diffusion is too slow a process. In order to burn more fuel in a given chamber the turbulence must be increased, as well as the surface of contact on which mixing takes place. It is also essential, however, that the whole of the cross-section of fuel- and air-streams takes part in this mixing, as otherwise part of the fuel is perhaps burnt quickly and at a high temperature whilst the remaining—and in some cases, possibly large—part burns only slowly and with little or no useful effect. Therefore, in the writer's opinion, the turbulence in the streams of fuel and air might prove to be of the same importance as turbulence at the surface of contact of both streams. This leads to a slightly different formulation of the requirements for quick mixing, *viz.* :

(*a*) Large vectorial difference of translational momentum of fuel and air streams, assuming that this is the essential factor (which includes the speeds of the streams and their angle) governing turbulence at the area of contact.

(*b*) Strong turbulence in both fuel and air streams themselves.

(*c*) Large area of contact between both streams.

It should be borne in mind, however, that this contention contains many points which are either uncertain or are insufficiently known of in a quantitative way. It would, for instance, not be superfluous to prove that vectorial difference of momentum is really the factor governing the mixing at the surface of contact, momentum being considered more essential than speed with regard to the burning of a stream of oil droplets. Nor would it be useless to know the influence of this factor quantitatively. In the case of the internal turbulence of fuel and air streams it would seem that high intensity (speed of rotation in the vortices) and large scale (diameter of the vortices) are required, but experimental confirmation of this supposition is definitely needed. Also, it is not sufficiently known quantitatively, what influence the speed of translation of a gas stream has on its internal turbulence, nor how far internal turbulence for a given speed of translation can be increased by suitable geometrics of the furnace or its ducts. This might prove to be important, in that a definite ratio between intensity and scale of turbulence at the surface of contact, and the same entities of the internal turbulence, might be required to avoid slow mixing and burning of the fuel and air in the centre of the streams, giving a long flame of low temperature. It is to these points, of at first sight more or less theoretical interest, that I would like to draw the attention

* For Discussion see *Journal of the Iron and Steel Institute*, 1947, vol. 156, Aug., pp. 501–504.

of the authors and perhaps of others, because it seems that along these lines a more clear picture would result which would also be of advantage in the study of the burning of oil and perhaps in the atomization of oil or tar.

Following the lines of thought described above, it would be interesting to know how the change of cross-section of the ports was effected, *i.e.*, to know whether with a change of cross-section also the surface of contact was changed. Further, those lines of thought suggest that, although with increasing air-port size for a given amount of gas and given excess of air, the speed-difference between air and gas is increased and thus the speed of mixing at the surface of contact, it does not follow that the average speed of mixing for the entire volume of air with the fuel is greater. This would require a very high level of turbulence in the air stream in the case of large air ports, because otherwise it will take a long distance of travel before all the combustibles have found the oxygen to combine with, as part of the air is a relatively long distance away from the gas stream. This would mean that with large air ports a sizable proportion of the fuel is burnt at low speed (long flame), and thus at a low temperature. In the experimental furnace of the authors this might not be felt, thus giving, *e.g.*, in Fig. 12, the highest efficiency with the largest air port, whilst in an actual furnace this influence would be felt strongly, because in an actual furnace the temperature difference between flame and bath (or even scrap, a short time after loading) is much smaller than in the experimental furnace. This means that parts of the flame which would not contribute to heat transfer in the actual furnace, still do so in the experimental furnace. In my opinion this would be a reason for being very careful in adopting some of the results on the experimental furnace, for practical designs.

Dr. **J. H. Chesters** (The United Steel Companies, Ltd., Rotherham) wrote : The paper by Dr. Leckie and his colleagues is a very modest statement on an extremely useful and fundamental piece of research on open-hearth furnace design that must have been very much more difficult to carry out than would be imagined by the casual reader of the paper. Dr. Leckie makes frequent reference to the paper by Mr. Thring and myself on " The Influence of Port Design on Open-Hearth Furnace Flames," but it should be pointed out in fairness to Dr. Leckie, that virtually all the work which he has published was done before our report was published, and much of it before our researches were even thought of. It is, however, very satisfying to see the extent to which the two quite different approaches tied in with one another. Our own feelings about the importance of carrying the right pressure under the roof are beautifully illustrated by Fig. 6, which is in good agreement both with the general theory of air infiltration and with the practical experience of many workers using roof-pressure control.

Work on furnace design might be divided into six stages as follows :

1. Mathematical calculations.
2. Furnace models using either air or water as simulative fluids.
3. Baby furnaces of the type used by Leckie.
4. Pilot furnaces such as might have to be constructed to take such radically new ideas, such as the one-way furnace, a stage further.
5. Trials on full-size furnaces using a large battery of special instruments and probes—as described in Special Report No. 37.
6. Long-term controlled runs on large furnaces as suggested by Mr. F. L. Robertson.

It is clear that the final answer must always be given by stages 5 and 6, but if all research starts from that end it may be a long time before real progress is made. New ideas are more likely to come from stages 1 to 3, and be confirmed or disproved in stage 4. The various approaches are in no way in conflict, but react on one another to further the general purpose ; thus mathematical calculation may suggest a new design, but model tests made on the basis of these calculations may show that the formulæ used are inadequate. Rummel has suggested formulæ to study mixing conditions, but these assume, *e.g.*, a steady air direction, which is hardly the condition existing in any open-hearth-furnace port. The calculation of the ideal position for the monkey-walls or knuckles is quite beyond the present technique, but could be studied by means of models. Similarly, the work that Dr. Leckie describes on furnace characteristics shows that our own work, as published in Special Report No. 37 would have benefited by more background tests on the effect of air/gas ratio, etc.

There are just one or two points that we should like to ask Dr. Leckie :

1. Could his present furnace be modified so that it could be used to study oil-burner characteristics, *e.g.*, the effect of such factors as steam pressure and oil temperature on downward heat flow ?

2. Is he really confident about the statements made on p. 419 regarding the effect of roof pressure on roof temperature ? Our own impression, which is apparently supported by Mr. Evans and also by certain American workers, notably A. J. Fisher, is that a high furnace pressure tends to be bad for the roof.

3. Does Dr. Leckie think that the furnace pressure could be controlled at a more con-

venient point than the centre of the roof? Certain of our brick-laying superintendents consider the presence of this initial hole in the roof to be a source of trouble and would prefer the pipe to be fitted in the front wall.

In conclusion, we should like to thank Dr. Leckie and his colleagues for this excellent contribution to the study of open-hearth furnaces, and hope that it is only the forerunner of many such reports.

Mr. **M. W. Thring** (The British Iron and Steel Research Association) wrote : (*I*) ***The Purpose of Model and Full-Scale Experiments***—One can distinguish four levels in researches into complicated systems such as the open-hearth furnace. These are :

(*a*) Purely theoretical investigation.
(*b*) Laboratory models.
(*c*) Intermediate models, and
(*d*) Experiments on the full-scale industrial plant.

Generally speaking there are three processes taking place in industrial furnaces, *viz.*, the heat-transfer process, the combustion process, and the aerodynamic (mixing) process. In a diffusion flame, however, these reduce to two, since combustion is completely controlled by aerodynamics, *i.e.*, the rate of mixing. We can consider the four methods of research in terms of their method of studying these two processes. Thus, (*a*) the purely theoretical approach can take account of the simultaneous heat transfer and aerodynamic process, but necessarily has to simplify the geometrical shape of the furnace system to a very high degree. (*b*) In laboratory models, such as water- or air-flow models of the open-hearth furnace, operated cold, it is possible to use a shape which corresponds, apart from small roughness effects, accurately to that of the full-size furnace, but in which only one of the two processes (in this case aerodynamic) is studied.

(*c*) Dr. Leckie here describes the use of an intermediate model in which the two processes of heat transfer and aerodynamics are studied simultaneously by a geometry quite accurately corresponding to that of the full-size furnace, but at a lower temperature. (*d*) In the full-scale experiments the two processes are both present, the geometry is exactly right and, in addition, the temperature and the working difficulties are all present.

Broadly speaking, one can see that as one goes up the scale from the first of these four methods to the last, it becomes more difficult to separate the effects of a single variable and obtain clear-cut answers, but on the other hand such answers as are obtained become more and more reliable in their application. It follows from this that the broad strategy of research on a system of this type should be advanced along all four lines. Thus the work of Dr. Leckie and his colleagues provides answers to such questions as port designs which are more reliable than those of laboratory work or theory, and more readily altered than those of full-scale research. The method is thus ideal for studying new alternatives for port design, particularly if it is carried out in conjunction with laboratory models of such ports by themselves. Such work is now being undertaken in the Physics Department of B.I.S.R.A. to back up the Shelton furnace experiments.

(*II*) ***Similarity in Furnace Models***—My first reaction to the idea of operating the furnace model at a relatively low temperature, was similar to that of many people, in that I felt it would invalidate the results. More careful investigation, however, has convinced me that this is quite untrue and that it is perfectly possible to apply similarity laws to a model of Dr. Leckie's type, although the method of application requires rather careful consideration.

Dr. Leckie is essentially concerned with what happens along the flame, *i.e.*, what fraction of its heat will be transferred to the bath as it passes along a furnace of given length. The aerodynamic process governs how quickly the heat is liberated by combustion, and heat transfer governs the fraction of the resultant sensible heat which is radiated to the bath. This means that, ideally, it is necessary to satisfy two similarity criteria : the Reynolds number, to make the aerodynamic processes right, and a thermal-transfer criterion $N$. Dr. Leckie has adjusted his rate of gas input to obtain correct values of the Reynolds number* in the gas port, but has in fact, when it is analysed, adjusted his heat transfer number, $N$, to approximately the same value as in the open-hearth furnace, by adjusting the thickness of the bricks on the bath (*see* p. 379), since he has chosen this size to give the right proportion of heat transfer to the bath. He has thus used a device for obtaining the second criterion at the correct value.

An alternative device would be to adjust the calorific value of the fuel gas and the oxygen content of the air by diluting them with flue gases so as to be able to adjust the heat input and the quality of gas flowing in, independently. This would probably be an appropriate method, since he has not adjusted the thickness of his roof to obtain the heat loss through the roof in the correct proportions between model and original,

* I rather think that the Reynolds number should be correct within the furnace rather than at the input, and hence that it should be calculated at the gas temperature after combustion in each case.

so that the model is similar as far as heat transfer to the bath is concerned, but not heat transfer to the roof.

(*III*) *Results of the Experiments*—The broad conclusions from these experiments seem to be very closely in line with Special Report No. 37, that open-hearth-furnace flames are too long (p. 421), and that the line of improvement is to obtain a port in which the mixing is so much better that the flame can be made shorter, while at the same time the excess air is reduced. Both lines of work show the extreme importance of reducing air infiltration, especially by raising the furnace pressure. Where this work is particularly valuable is in the ability to try out a number of different port designs, and to show which gives the best mixing. The second paper of this series and the more recent work which is now proceeding, carries this aspect very much ahead of Special Report No. 37, confirming the value of proceeding with both types of work side by side.

I feel that the theoretical analysis based on Rummel's work given in Fig. 14, is extremely stimulating but requires verification, probably by means of aerodynamic models in the laboratory, before the conclusions drawn from it can be accepted with certainty, and of the two lines for immediate improvement, given on p. 417, I am personally of the opinion that an increase of the gas pressure in the uptakes, coupled with a smaller gas port to give a higher velocity, would involve improvement in almost every open-hearth furnace where it is practical to introduce it.

## AUTHORS' REPLIES

Mr. **D. Kilby,** in reply wrote : I was pleased to gather from Mr. Geary's remarks that he had arrived at the same conclusion as myself, regarding the ease of operation of the coke-oven-gas-plus-illuminant fired open-hearth furnace, when compared with other types of gas-fired open-hearth furnaces.

Mr. Geary expresses doubt as to whether or not a composite gas-plus-liquid-fuel burner will operate with equal efficiency, using either 100% of gaseous or 100% of liquid fuel. I agree that each burner has a liquid–gaseous fuel mixture range, which gives a measure of flexibility. Outside this range a loss of efficiency takes place. If it is decided to work outside the normal range for which the burner is designed, two courses are open. In the first place, if the deviation from the normal fuel mixture is not too great, modifications to the burner can be made, such as the insertion of hollow machined cones in the gas-tube nozzle to reduce the bore of the gas outlet, to maintain gas velocity on a reduced gas input. The second course is to change the burner completely to suit the fuel-mixture conditions. This is done in 15–30 min., without loss of output. It is done, for example, when a change is made from 25% of liquid fuel to 100% of liquid fuel, or *vice versa*.

Replying to Mr. Geary's remarks on fuel input during the charging period, campaigns have been worked during which 85,000 cu. ft. of coke-oven gas per hour have been burnt in the charging period with the object of improving output, etc. Whilst some increase in output was obtained, fuel consumption per ton of steel was higher and furnace campaigns were shortened, with more frequent repair periods. Also, the increased amount of coke-oven gas used upset the fuel balance on the rest of the shop. At the conclusion of these campaigns it was decided to revert to the 60,000–65,000 cu. ft. of coke-oven gas per hour during charging.

Dealing with instrumentation, all the furnaces now have gas and air recorders and indicators, liquid-fuel indicators and integrators, and steam- and oil-pressure gauges. Apart from these instruments, one of the furnaces has a roof-temperature indicator and recorder, a steam meter, a roof-pressure recorder, and automatic damper control.

The furnaces are worked at a roof pressure of 0·06 in. (W.G.).

Samples of waste gas taken at the top of the regenerator chamber contain 10–14% of carbon dioxide.

Mr. Whitfield raises the question, "Why atomize with steam ?" I think, in most cases, it is a matter of using that which is most readily available, and in such circumstances it has usually been found the most economical. To my knowledge most operators who have used air for atomization of liquid fuel on open-hearth furnaces, have had a considerable amount of trouble with stoppages in the burner nozzle. This may be the reason why the American operators do not appear to use air to a great extent for atomization.

The object of allowing a small amount of steam to pass through the burner not being used, is to make sure that the pitch–creosote tube is emptied completely of liquid fuel, and to stop the tube from becoming made-up with carbon.

In reply to Mr. Whitfield's question on regenerator insulation, I would say that none of the regenerators on the furnaces under discussion were insulated.

Dr. **A. H. Leckie** wrote : It is clear that

Ir. E. de Graaf has made an independent and careful study of the problem of mixing and combustion in diffusion-flame furnaces, and his contribution to the discussion is of great value to us.

We are reminded that in the Shelton experiments the effect of port angle was not investigated, neither was cognizance taken of the ratio circumference/area at the mouth of the port. The actual method used in varying the port sizes is indicated in Fig. 20 of Part II. Regarding port angles; where the angle between the gas and the air port directions is small, as in the " ordinary " block, the conclusions on port design reached in the paper are valid, subject to the proviso that increasing the angle between the ports does, in general, assist mixing. When the angle between the gas and the air directions entering the furnace is large, as in the Maerz furnace, the conclusions of the present paper need modification, and the results obtained with the Maerz furnace will be communicated as Part III of the series.

The actual geometric distance of the axis of the air stream from that of the gas stream (affected by the shape of the air port) may have some effect, but reference to the work of Davis, p. 422, ref. 6) which considers the mixing of an air or gas stream with stationary air (*i.e.*, the surrounding layer of air is of infinite thickness), suggests that the turbulence of a rapidly moving injected stream is sufficient to draw in large quantities of air from a considerable distance. Thus, it is likely that the advantage of a large air port in securing considerable difference between the gas and air velocities outweighs any disadvantage in removing the axis of the air stream further from the gas. Nevertheless, it would seem desirable to obtain the large air port by surrounding the gas as far as possible (*i.e.*, the so-called " open block " construction*). This does not affect the recommendation that where pressure permits, the large difference in velocity should be secured by increasing the gas velocity in addition to, or even in preference to, decreasing the air velocity.

We should like to thank Dr. Chesters for the kind remarks made at the beginning of his contribution. It is obviously advantageous for two researches with similar objectives to be conducted at the same time, with exchange of essential information. Nevertheless the link should not always be too close, otherwise the line of thought of one team of investigators may be unconsciously biased or prejudiced by the results of the other work. I think the conduct of the work at Templeborough and that at Shelton was on the optimum plane of contact—Dr. Chesters' team and the B.I.S.R.A. team knew what each other were doing, and occasional joint consultations were held, but each investigation was conducted entirely independently, and therefore the fact that the main conclusions are similar is doubly significant.

Dr. Chesters' specific points may be answered as follows :

1. The existing furnace could be used to study the variables affecting oil burning, as oil firing equipment could be installed with little difficulty. Such equipment is already installed for providing small oil additions with a view to increasing flame luminosity but this would need to be modified for 100% oil firing. When the furnace was first constructed in 1944, and the programme formulated, oil firing on any large scale had not been contemplated for the British steel industry, and perhaps the gas-fuel programme, which is still far from complete, may have to be curtailed to permit experiments with oil, that is, unless work with oil can be started elsewhere.

2. With regard to the effect of roof pressure on roof temperature, we have been careful to state that the conclusions on p. 419 are only tentative. At the time of writing this reply (July, 1947) many more results are available, and whilst some experiments have confirmed the original finding that high roof pressures decrease the roof temperatures, others do not show this effect. However, in nearly all experiments the roof temperature does not rise greatly within the higher ranges of roof pressures, although the heat transferred to the bath does. Much depends on port design and on the design of the working chamber, and it is hoped to publish these results together with the other experiments with a Maerz block within a few months.

In many production furnaces the use of a high roof pressure does tend to damage the refractories. Today most furnaces are operated to the maximum rate of heat input the furnace will stand, and the effect of increasing the roof pressure is to diminish infiltration of cold air to such an extent that the roof may be damaged unless the fuel input is reduced appropriately. Thus, in high-production practice the effect of high roof pressure should be to save fuel, but most furnaces are not yet capable of control to such a degree of precision that the ' buffer effect ' of slight air infiltration can be dispensed with.

3. The installation of the point of pressure measurement in the roof is now such common practice that it may be considered established that no structural trouble is caused. There would appear to be no objection to a wall installation, but it must be remembered that the internal pressure is very small and requires a sensitive

* A good photograph of this type of block is given by Sarjant and Barnes in Plate XX (p. 256) of Iron and Steel Institute Special Report No. 22.



XUM

instrument. It is therefore desirable to take the measurement at the highest point in the working chamber, where the pressure is also highest. Also, a wall fitting may be more affected by obstruction due to ' running ' of refractories. However, a few wall installations are in existence and are said to be satisfactory.*

Mr. Thring's contribution to the discussion is particularly welcome since it is put forward by one who has made a special study of the similarity problems involved in model experiments on combustion and heat transfer. The fact that Mr. Thring finds no serious fault with the procedure adopted at Shelton is therefore gratifying. It is a little difficult to appreciate his argument that Reynolds numbers should be calculated at the temperatures within the furnace rather than under the conditions at the end of the gas port, since once the flame has developed, mixing has already taken place. It would seem, therefore, that this argument implies that the conditions after a particular event (*i.e.*, mixing and combustion) can control the course of that event, and whilst this may be true in many cases, I doubt if it can be so with turbulent mixing.

However, this is a minor point and does not affect the results obtained at the Shelton furnace.

Needless to say we are in entire agreement with Mr. Thring regarding the various methods of conducting research on the problem ; we have already considered our results in the light of the work on production furnaces described in Special Report No. 37, and are awaiting with interest the results of Mr. Thring's work in the B.I.S.R.A. Physics Dept., with laboratory size models.

* R. C. Baker, *Journal of the Iron and Steel Institute*, 1947, Sept., p. 81-88.

## Correspondence on the Papers—
## THE APPLICATION OF SLAG CONTROL AND AN INVESTIGATION OF BASIC OPEN-HEARTH SLAGS† *by T. Fairley*
## and—THE EFFECT OF TEMPERATURE ON THE PHOSPHORUS REACTION IN THE BASIC STEELMAKING PROCESS† *by K. Balajiva and P. Vajragupta*

Dr. **P. Vajragupta** (Sheffield University) wrote : Dr. Fairley's paper is interesting in that it gives a clear and straightforward method for slag control, but it seems unlikely that the method can be directly applied in other works, since some of the assumptions appear to be based on the local steelmaking conditions. It has been assumed, for example, that the lime content of the slag is 50%, but this is not always true. Again, there appears to be no physico-chemical justification for the view that an optimum sum of 18% of $SiO_2 + P_2O_5$ in the slag gives a phosphorus content in the metal of 0·035%, and it may be misleading to suggest that this is so. Indeed, in our own laboratory work it was possible in many cases to reduce the phosphorus content to less than 0·035% with slags containing more than 18% of $SiO_2 + P_2O_5$, and in order to reduce the phosphorus content to a low level it was not always necessary to use unduly viscous slags of high lime content. In fact the experimental results showed that satisfactory dephosphorization could be obtained by employing slags containing much less than 50% of lime, provided that the Fe and $P_2O_5$ contents were properly adjusted.

It is a pity that Dr. Fairley has ignored the effect of temperature, since it is clear that this factor must be taken into account for effective control of the steel bath.

The various opinions quoted by the author with reference to the optimum value of the slag basicity are illuminating, for they indicate the shortcomings of this method of approach to slag–metal problems. Basicity, no matter how it is expressed, can only give a one-sided picture of the actual refining process, which involves reversible reactions taking place between the slag and metal layers. Before scientific control of the steelmaking

† For Discussion see *Journal of the Iron and Steel Institute*, 1947, vol. 156, Aug., pp. 505–510.

process is possible, however, more information is needed concerning slag–metal equilibria, as well as knowledge of the physical chemistry of the liquid slags themselves. In this respect the author would have done a useful service if he had published more slag and metal analyses of the samples taken.

Complete analyses for slag and metal are given in only one case, and it is interesting to note that when this result is plotted on the basis of log $\Sigma$ CaO against log $k$ for the phosphorus reaction it fits in almost exactly with the line which Dr. Balajiva and I gave for 1585° C.

Since Dr. Fairley did not record the temperature, too much importance should not be attached to this apparent agreement between laboratory and industrial results.

## AUTHORS' REPLIES

Dr. **T. Fairley** : I thank the various contributors for their comments, and I support Mr. Bacon in his plea for further work on slag–metal reactions and slag control. If a slag finishes with 18% of ($SiO_2 + P_2O_5$), then such a slag is suitable for the normal reduction of sulphur, provided that the other additions are correct. In reply to Mr. Mitchell's query about the necessity for control, I have to say that this method of control has given improved outputs, and the more control we have over the process the better results we shall get.

The *p*H method for the determination of slag basicity, as mentioned by Dr. Reeve, is interesting, and one hopes that some such scientific method will replace the visual examination of slag pancakes.

In reply to Dr. Vajragupta, although all finishing slags do not contain 50% of lime there are many melting shops where this assumption may be made and this method of slag control used with beneficial results. Experience shows that when a slag finishes with 18% of ($SiO_2 + P_2O_5$), then the phosphorus is reduced to the required value and the ingots from the end of the cast do not show any appreciable increase in phosphorus. Dr. Vajragupta says that satisfactory dephosphorization can be obtained by employing slags containing much less than 50% of lime, provided that the Fe and $P_2O_5$ contents are properly adjusted. It must be appreciated that to make good-quality steel the Fe values must lie within a very narrow range, and therefore such adjustment of Fe and $P_2O_5$ is not possible.

Dr. Quarrell and Dr. Vajragupta ask for full details of the slag and metal analyses. This information is too lengthy for publication, and copies have been sent to them.

Drs. **K. Balajiva** and **P. Vajragupta** wrote : we wish to express our thanks to all those who have taken part in the discussion.

With reference to Mr. Bacon's criticism of the way in which we included 10 results of the high-alumina series with the rest in working-out the phosphorus equations for 1585° C., we should like to refer him to the answer which we made concerning this point in our reply* to the written discussion on our earlier paper. However, it seems desirable to emphasize once again that the inference which was drawn from the statistical test was simply that, within experimental accuracy, the presence of $Al_2O_3$ up to 8% had no significant effect upon the relationship established, and its effect up to that limit was therefore considered to be too ambiguous to justify any definite conclusion. In view of this finding it appears that higher percentages of alumina would have to be employed in order to assess the real effect, and this problem deserves further investigation.

As regards Schenck's equation, although Mr. Bacon has found it very satisfactory, it by no means implies that it is so in general, especially in view of the fact that there have been reports to the contrary, *e.g.*, in the work of Maurer and Bischof,† among others. The scientific value of Schenck's method is further weakened by its assumptions regarding liquid-slag constitution, which will be found to be most improbable according to recent experimental evidence, and it seems strange that the assumption of either tri- or tetra-calcium phosphate yields an equally applicable equation.

In applying Schenck's method to the last two of our results Mr. Bacon found wide disagreement, and he attributed this to the difference between industrial and laboratory conditions. We do not know how far one can accept Schenck's equation as a criterion, but we can say that the present experimental data were obtained under conditions closely similar to industrial practice. Although nitrogen streams were employed during the melt, an oxidizing atmosphere still existed, as may be judged from the fact that the slag often contained more iron than originally intended. As for the slag bulk, that should not make any difference if the law of mass action applies to slag–metal systems, and there is a great deal of evidence in support of this view. Further, there are reasons for believing that our results represent the actual dephosphorization process as it should be in the

* *Journal of the Iron and Steel Institute*, 1946, No. I, pp. 148P–150P.

† *Journal of the Iron and Steel Institute*, 1935, No. II, pp. 13–42.



XUM

steel bath under equilibrium conditions, for not only do they bear consistent relationship among themselves, but they also empirically indicate the physico-chemical law underlying the phosphorus reaction. In industrial practice, on the other hand, equilibrium conditions are not always attained, because of the viscous nature of the slags containing high lime and low iron oxide often employed and the fluctuations caused by furnace additions.

We are glad that Mr. Bacon has applied our equation to six of his basic open-hearth data and obtained some fair agreement. Concerning the first sample given in Table A, we wonder how he arrived at the figure 0·051 for the phosphorus, because our equation gives a much higher value if the temperature is actually 1627° C. As for the last sample belonging to the high-carbon group, no comparison can be made in the absence of temperature records. However, we hope that more industrial data with reliable temperature records and control will be treated in the manner we have suggested before passing any definite verdict.

We thank Dr. Quarrell for his remarks and for the interest he has taken in the work. We are also grateful to Dr. White for his constructive criticism and the way in which he has clearly brought out the theoretical implication of Fig. 35 of our first paper. In fact, it was found possible to prove from the empirical relationship established that there was a maximum value of $(P_2O_5)/[P]$ at a critical (CaO)/(FeO) ratio, but through an oversight this point was not mentioned.

We agree with Dr. White that a complete solution of the phosphorus reaction can be obtained only by a rigorous treatment of the results in terms of the mass-action law. Since our knowledge of the liquid slag as regards compound formation and dissociation is far from satisfactory, the method of trial and error has to be resorted to in the calculation of the activities of the reactants, as is illustrated by that interesting work of his, but in the present case matters are further complicated by the presence of calcium phosphate in the slag.

As regards Mr. Kerlie's point, we think he has made a mistake by plotting [O] against (FeO) without taking into account the effect of temperature, because, according to previous work on the subject and especially that of Körber,* $L_{FeO}$, the partition coefficient of FeO, was found to vary with the temperature. It will be seen also from Fig. 7 of the paper by Winkler and Chipman that their results, when plotted with proper temperature corrections, support the view that the oxygen in steel is proportional to the FeO in the slag. There appears to be no ground therefore for substituting $(FeO)^{5/2}$ for $(FeO)^5$ in the equilibrium expression, and Mr. Kerlie's explanation of the gradient thus obtained in terms of the basicity of the slag is somewhat arbitrary.

* *Stahl und Eisen*, 1932, vol. 52, p. 135.

## Correspondence on—

## THE FIRST REPORT OF THE ROLLING-MILL RESEARCH SUB-COMMITTEE (Special Report No. 34)†

## and on the Papers—FLUCTUATIONS OF THE DISTRIBUTION OF TORQUE BETWEEN ROLLING-MILL SPINDLES† *by E. A. W. Hoff*

## and—THE APPLICATION TO SHAPING PROCESSES OF HENCKY'S LAWS OF EQUILIBRIUM† *by E. Siebel*

Mr. **G. E. Tanner** (Appleby-Frodingham Steel Co., Ltd., Scunthorpe, Lincs.) wrote : As one who comes into daily contact with the problems caused by the mysteries of rolling, I should like to congratulate all those responsible for this very interesting Report, in so far as it is a very welcome start towards the unravelling of some of these mysteries.

The information contained in the Report is very interesting, but there is really very little that has yet reached such a stage that it can be of any real practical assistance to a roller or to the

† For Discussion see *Journal of the Iron and Steel Institute*, 1947, vol. 156, Aug., pp. 511–522.

rolling-mill management. The lines on which the Committee are working, however, indicate that before very long a great deal of information of very practical value will be available.

In Section 5 a simple method of calculating roll pressure is given. This method, although undoubtedly very much simpler than the more usual formulæ is, of course, of little value to the mill operator. How very much simpler it will be when the day comes for a roller to be able to read off a dial or illuminated scale the actual roll pressure at each pass. He will then be able to apply the maximum draft on every pass within the limits of safety for the mill equipment. The only other limiting factor will be the deformability of the steel. As with larger and more constant drafts the temperature should remain higher throughout the rolling process this factor will be of less consequence and the throughput of existing mills should increase considerably. In this connection I should like to ask the authors if the roll-force meter described has yet been installed as a production instrument and, if so, with what results.

The description of the experimental cold-rolling mill is very interesting and I hope it will not be long before a similar mill for hot-rolling experiments is under construction.

Mr. **J. S. Caswell** (University College, Swansea) : This excellent Report is valuable for the foundation which it provides for further investigations. Our neglect in this field of enquiry is reflected in the very few references to British investigations. With so large a Report, comprehensive discussion is impossible, and these comments are confined to a few special points.

*Power Losses*—A power loss, not referred to by Dr. Underwood and Dr. Ford, is that consequent on the misalignment of the machine elements comprising the drive from the power unit to the mill rolls. In the nature of mill operation generally, vertical misalignment from the pinions to the rolls cannot be avoided, and properly designed couplings minimize the loss. But serious losses of power can occur with the cruder form of wobbler-box coupling, and also in those cases when misalignment is unintentional but consequent on the wear of brasses, the settling of foundations, and poor mill-wrighting. In a cold-roll mill-train, overhauling of alignment, because of engine overloading, made it possible to *add* an extra mill to a four-mill train *without* overloading the engine. These losses are not easily noticed because when the mill is empty, the total power losses are light, and when the mill is rolling, the increased misalignment losses are largely masked by other power losses.

Having regard for accuracy, it is perhaps worth noting that a small loss arises from the continuous input of strain energy into the rolls to maintain the cyclical reversal of the roll deflections, *i.e.*, the maintenance of a fixed flexure in space while the rolls are turning.

*Roll Stresses*—No doubt space limitations prevented Dr. Underwood from making adequate comment on the earlier customary basis for calculating the stresses in rolls (p. 51). In view of our greatly increased knowledge of the behaviour of metals, stress analysis now requires more care in approach. Initial internal stress, roll-face compression, surface finish, rates of thermal change, crazing, fire-cracking, roll-pass profile, and the radial variation of the physical properties of the roll material, are just a few of the factors which have an important bearing on any estimate of the stresses that may be expected in rolls.

*Roll Deflection*—The writer would like to thank Mr. Larke for noting the slip in the formula for the longitudinal stress deflection at the edge of the strip. The writer has re-checked the calculation and confirms the corrected form given on p. 51.

*The Experimental Mill*—The equipment and instrumentation of this mill is an important and well-planned development. The comments made by Dr. Ford (p. 88) are disturbing, however, in view of the extensive efforts made to achieve accuracy. Under such conditions, a problem such as that concerned with the effect of using rolls of smaller or larger diameter could not be investigated with accuracy, because with the necessity of changing rolls, it would be quite uncertain whether a change in power readings could be attributed to a change of roll diameter. As Dr. Ford has commented, the torque-meters must be the chief means for examining what happens between the rolls, and with simultaneous speed records, more reliable power readings could be obtained. When operating plant of these dimensions, it is often too inconvenient to wait until stable thermal conditions are established in the motors, in the bearings, etc., and that is a further reason for putting greater dependence on the torque-meters.

*The Measurement of the Roll Force* (Section IV)—The critical examination of the various methods of measuring the roll force is a very useful contribution to the Report, and the application of electronics for this purpose is ingenious. But, after noting the considerable detail relating to the excellently evolved electromagnetic gauge, one is tempted to enquire whether this electrical method of measuring the mechanical strain is, in

all respects, superior to the customary method of measuring strain by mechanical means. The authors would know that one of the important principles in engineering method is to reach an end efficiently by the simplest possible means, and both mechanical and electrical engineers are apt to overlook this sometimes. The electromagnetic gauge is basically a strain gauge in which the elastic element—the short steel ring—undergoes a change of length that may amount to 0·0021 in. In material-testing laboratories total strains of this order are regularly and easily measured with accuracy by means of micrometer dial gauges possessing an open range of scale corresponding to that shown in Plate X and on p. 112. Although unsuited for severe shock, gauges of this type if suitably mounted adjacent to the elastic element should be quite satisfactory for the experimental mill, and they would be little affected by the mild shock which occurs when the strip enters the 'bite' of the rolls. These gauges are inexpensive, accurate, and robust, and calibration is easy. The chief disadvantage, compared with the electromagnetic gauge, is the necessity of reading the dial at the point of location of the gauge. But this would not be a serious difficulty on the experimental mill and other mills of similar type.

The discussion on strain gauges on p. 98 refers to the type of strain gauge fitted to the housing. The writer would like to suggest to Mr. Douglas and Dr. Ford that they give consideration to devising a combined mechanical and electrical type of roll-force meter, which incorporates the mechanism of the micrometer dial gauge and the elastic element placed under the mill screw. The foregoing criticisms are not intended to apply to the numerous special cases where the electromagnetic gauge has undoubted advantages for measuring roll forces.

*Rate of Compression*—In Section V, pp. 125 and 135, there is apparently a slight omission which may be misleading. The term $V$ is simply defined as "the volume of material rolled per second," whereas the expression for $\lambda$, p. 135, implies of course that $V$ relates only to unit width of stock, Dr. Orowan's work is of far-reaching importance, and his simplification of parts of his classical paper, read before the Institution of Mechanical Engineers, is valuable for the purposes of those who are daily concerned with rolling-mill practice.

*Roll Torque, p. 142*—All the calculations relate to rolls mounted in frictionless bearings. In this form the calculations are useful for analytical purposes, but to serve practical ends, it would have been a useful addition to have included a final expression for the roll torque which would include an additional term to cover the effect of that ever-present care, *viz.*, roll-neck friction.

*Relative Importance of Problems of Enquiry*—There is a varying degree of urgency for the solution of rolling-mill problems. While many of the investigations discussed and planned are important, the wide application of electrical drives for rolling mills has given rise to a large amount of reliable data in respect of the power requirements under a variety of rolling conditions, and thus rendered some investigations less urgent. In the writer's opinion the most urgent problems are those concerned with the quality of rolls as metal-deforming tools. They are expensive, complex in structure, troublesome to instal, subject to severe applied loading and thermal strain, sensitive to wear and surface fatigue, liable to fracture, and cause considerable supplementary damage and loss of output. An experimental mill provides only a partial solution of some of these problems. There is need for field work in the form of organized observation and record in both the manufacture and the use—and perhaps the misuse—of rolls.

*Training*—In these days of the rapidly increasing application of science to industry, there is need for more engineering training in the various matters connected with the rolling of metals. In metallurgical books there has been a tendency to refer to mechanical plant in a descriptive manner, and in engineering books, of the textbook kind, rolling mills and metallurgical plant have not been common subjects for analysis, in the manner associated with turbines, gas engines, etc. In due course there should be a close approach to the same precision and excellence in rolling-mill plant and operation as one ordinarily expects to find in the turbines, generators, motors and some of the steam engines that supply power to the rolling mills.

*Standardization*—With the appearance of this First Report, it is perhaps opportune to urge the adoption of standard notation and the use of British units of measurement throughout subsequent reports. There is also special need for standardization of many parts of rolling-mill plant.

The members of the Rolling Mill Research Sub-Committee, the authors, and others concerned with the production of this Report deserve high praise for this excellent beginning in this important field of the British iron and steel industry.

Dr. Hoff's paper opens up a matter which has been hitherto almost completely obscure. The torque-meters are superbly sensitive to changes of torque and are very well suited for examining some of the elusive phenomena related to the deformation of metal between rolls.

The explanations for the irregularities seem to

be hardly adequate, however, and it is evident that it is necessary to examine these further when the same material, each time initially in the same physical condition, with the same width and draft, is rolled at the same speed under different conditions.

The writer would like to suggest, also, the examination of the following in subsequent investigations.

(1) The effect of driving to the bottom roll only, as is common in the tinplate industry, all other conditions remaining the same, and compared with driving to each roll.

(2) An estimate of the pure rolling torque on the basis of the following :

Use strip almost as wide as the roll face, or use rolls machined down along the face until the actual rolling face is only slightly wider than the strip. Rolls set for a given draft.

Let $P$ = Roll load (separating force between the rolls),
$T_1$ = Total torque, in case (i),
$T_2$ = ,, ,, ,, ,, (ii),
$T_3$ = ,, ,, ,, ,, (iii),
$T_f$ = Roll-neck friction torque, under load $P$,
$T_r$ = Apparent pure rolling torque,
$T_x$ = Supplementary torque, consequent on pressing the rolls together in case (ii),
$T_{pr}$ = Pure rolling torque.

Case (i) : Roll strip, and note the total torque $T_1$ and the roll load $P$. Then :

$$T_1 = T_r + T_f \quad \ldots\ldots(1)$$

Case (ii) : Press the rolls together with a force $P$, *i.e.*, equal to the roll load in case (i). Then :

$$T_2 = T_x + T_f \quad \ldots\ldots(2)$$

Case (iii) : Eliminate rolling contact of the rolls, and apply separating forces of amount $P/2$ between each pair of upper and lower roll necks. (Certain types of bearings permit this to be done.) Then :

$$\tfrac{1}{2}T_3 = T_f$$

The pure rolling torque would then be closely represented by :

$$T_{pr} = T_r - T_x = T_1 - T_2$$

and the supplementary torque by :

$$T_x = T_2 - \tfrac{1}{2}T_3$$

It may be that $T_x$ is too small to be noticeable, in which case :

$$T_2 = \tfrac{1}{2}T_3 \text{ and } T_{pr} = T_1 - \tfrac{1}{2}T_3.$$

## AUTHORS' REPLIES

Dr. **H. Ford,** in reply, wrote : With regard to the cold-rolling process, we have had some very interesting comments from Dr. Lee, Mr. Hill and Dr. Orowan, and they have propounded some new conceptions which are obviously going to be further headaches for the engineer who has to interpret them in terms of the practical problems of cold-rolling.

The work of the Rolling-Mill Research Sub-Committee has been considered as being two-fold : first, the study of the fundamentals of the rolling process, and second, the interpretation of the theories and basic facts in relation to industrial rolling-mill design and operation.

So far, the experimental work carried out at Sheffield under the second of these headings has reached a point where a large number of measurements over quite a wide range of cold-rolling conditions have been made, and we have been able, by the use of Dr. Orowan's theory as presented to the Institution of Mechanical Engineers, to sift out the best method, from the many which have been proposed from time to time, for practical calculation purposes. The object has been to choose those which should be short and easy to use, and should be capable of reasonable accuracy over a definite range of rolling conditions. A paper on this work has been prepared and I think it will be agreed that we have put forward simplified methods based on these theoretical studies which satisfy the practical requirements.

With regard to Mr. Tanner's interesting remarks it is agreed that the work described in the First Report has not yet reached a point where the average roller can make use of it, but it is confidently believed that the experiments, and their interpretation referred to in the foregoing paragraph, will go a long way to meeting the criticism.

I entirely agree with Mr. Tanner that a reliable roll-force meter is a very necessary addition to any rolling-mill, and if the best output from and most intelligent use of existing mills are to be secured, the roller requires such an instrument. This was one of the objects in developing the roll-force meter described in Section 4 of the Report, and Mr. Tanner may be interested to know that this apparatus has been used already on several industrial equipments with most promising results. The fact that recorders as well as indicators are fitted, allows the rolling conditions for 24 hr. per day for weeks or months on end to be permanently recorded, and the records can be examined at leisure.

It should soon be possible to provide Mr. Tanner with the instrument he—very rightly—is asking

for, although such an instrument will not be cheap.

It would indeed be very useful to have hot-rolling equipment for experimental work, but so far there has been insufficient support for the idea.

Mr. J. S. Caswell has made several useful comments. With regard to the power losses in the experimental mill, the accuracy of the readings as far as the essential process of rolling is concerned, is unaffected by the variable nature of the losses in the motor and gearbox. The tension meters were fitted to overcome this source of inaccuracy and it was in fact found that the roll-neck bearings' losses could be adequately determined by calibration tests similar to those described in the Report. The losses in the drive are really incidental to the basic problems of energy consumption in rolling, since there is no standardization in mill drives and an exact knowledge of the losses in the Sheffield mill would be of little interest to the designer. Even if these are of interest the variations mentioned in the Report actually exist—the apparent anomalies are not inaccuracies in the methods of measurement. Mr. Caswell can be assured that all power consumption values in our researches are computed from the torque-meter readings and the speed readings.

Regarding Mr. Caswell's remarks on the roll-force meter, it is true that normally the simplest solution of an instrument problem is the best, but this depends upon what is required from an instrument—the degree of accuracy, the speed of response, the reliability, the robustness, the magnitude of the indicating force or current, and so on. It is not possible to supply all these desiderata without the aid of electrical transmission and amplification, as anyone who has had experience of instrument development work will appreciate. Mr. Caswell himself has put his finger on the weakness involved in the gauge he suggests —the shock loading, both at entry and exit of the strip. Moreover, two such meters would have to be read, along with the seven or eight other individual readings, and, as in many cases only a few seconds can be allowed for a reading, a large number of observers would be needed to read instruments in this way. Again, an instrument for industrial as well as laboratory work was required, and the simple mechanical instrument proposed would hardly be practical, nor would it provide a continuous record.

Dr. Orowan has confirmed that the term $V$ is indeed the volume of material per unit width rolled per second.

The suggestions as to problems for enquiry and in relation to training are certainly to the point, and I think Mr. Caswell will find that these points are already well appreciated and are in fact being dealt with.

There is one further remark which I should like to make, with regard to what the President said about those who contributed to the initiation of rolling-mill research, from the fundamental and practical aspects. The manufacturers of plant—both the manufacturers of rolling-mill plant and those of electrical equipment—contributed heavily in funds and in kind, towards the cost of these researches.

Dr. **L. R. Underwood** wrote: Mr. Brown very rightly emphasizes the importance of friction in the rolling process. The question whether the coefficient of friction between the rolls and the material is a constant for any given set of conditions or whether it varies from point to point along the arc of contact is important on account of the effect it will have on the shape and size of the friction hill as a whole (and consequently on the roll load and deformation torque) rather than on account of its effect on the pressure peak only. It is usual to assume that the coefficient of friction is constant because there is no real knowledge of how it varies along the contact arc or, indeed, whether it varies at all. Until this matter is settled, attempts to estimate the accuracy with which the roll load can be calculated by means of friction-hill theories by comparison of the load calculated on the assumption of constant friction with experimentally measured roll loads, must be unconvincing. It is, therefore, much to be desired that an intensive study of friction in rolling should be made by all methods available, although admittedly the subject is one of great difficulty.

Mr. Brown's statement that up to the present time every writer on rolling has assumed without question that friction is constant throughout the contact arc is not strictly true. Nadai,[1] writing on roll pressures in cold-rolling, definitely considered the case of variable friction, and earlier, in the case of hot-rolling, Hitchcock[2] proposed an empirical equation which he thought might represent the probable variation of friction along the contact arc.

Similarly, the statement that the Ekelund theory was based on the assumption of slip between the rolls and the material everywhere except at the neutral point is not quite correct. What Ekelund assumed was that there was slip between the plane of entry and the neutral point and 'sticking' or shear between the neutral point and the plane of exit. It is this arbitrary distinction between zones of slip and no-slip that gives rise to the peculiar shape of the peak of the pressure diagram that can be deduced from the Ekelund theory.[3]

One wholeheartedly agrees with Mr. Tanner in his remarks on the desirability of having all rolling-mills fitted with load-measuring devices. At present this ideal is not attainable, as load gauges suitable for the wide range of requirements found on mills of all types and having the necessary qualities of robustness, constancy, relative simplicity, and cheapness are not available, although satisfactory instruments for certain mill sizes can be obtained, but perhaps not quite as easily or cheaply as might be desired.

A roll-load gauge is not, however, by itself a complete safeguard against damage to the mill due to overloads, as the condition may arise in which the roll load is within the design capacity of the mill whilst the roll torque is excessive. This condition is liable to occur with heavy reductions and thick materials and is more common on 4-high mills than on 2-high mills owing to the relatively small work rolls and pinions on the former. Subject to this limitation a roll-load gauge used as Mr. Tanner describes should be an asset to the roller.

In dealing with the method of roll-load calculation described in Section V, Mr. Tanner states that this is of little value to the mill operator. If, by mill operator, is meant the roller this statement is presumably true, as one hardly expects the roller to use somewhat complicated mathematical methods to decide his pass schedule. Methods such as that described in Section V, if reliable are, however, of considerable assistance to mill managers in planning pass programmes, for by their aid the most advantageous set of passes from the point of view of roll load and power requirements can be found, due regard being paid in selecting the passes suitable to the deformability of the material rolled. Probably greater use is made of this procedure on the Continent than in Great Britain.

Mr. Caswell has submitted a number of valuable comments and suggestions, some of which are dealt with below.

*Power losses*—The case quoted by Mr. Caswell to illustrate the possible magnitude of the power loss due to misalignment, is interesting. Details of the particular plant have not been given, but since it included a steam-engine drive it was presumably not of recent origin. It may safely be said that in the vast majority of modern rolling-mill plants considerable care is taken in the design, construction, and erection to ensure that the parts are correctly aligned and the foundations adequate. Under these conditions the power loss due to misalignment is usually negligible.

*Measurement of roll force*—The writer fully agrees with Mr. Caswell that, other things being equal, a simple mechanical device for measuring roll force is to be preferred to the somewhat costly and complicated electrical instruments. As no doubt Mr. Caswell is aware, numerous attempts to produce a simple roll-force gauge have been made and a recent example is the Johansson gauge, which has been used with reasonable success for commercial mills in Sweden. As a point of interest it may be mentioned that on a 13-stand hot-mill at present under construction by the writer's firm, each of the stands is to be fitted with gauges of this type.

The well-known method of placing a hydraulic cylinder connected to a Bourdon pressure gauge under the mill screws has also been used with satisfactory results on several cold-rolling mills in Great Britain. This method is reasonably cheap, reliable, easy to calibrate, and sufficiently accurate for works use. Referring to Mr. Caswell's proposal to mount a micrometer dial gauge on a short steel ring for roll-force measurement, one practical difficulty not mentioned may arise. If the load on the ring is not axial, and axiality under rolling-mill screws cannot be ensured on account of various causes such as essential clearances between the chocks and housing windows, etc., then the strain will not have the same magnitude at all points around the ring and consequently several dial gauges would have to be arranged on the ring so that a closer indication of the average strain could be obtained. This difficulty complicates the use of the gauge on mills even under laboratory conditions.

*Training*—The absence of good text-books on the design and construction of rolling-mills is to be regretted, as their absence undoubtedly makes it much more difficult for young engineers and mill designers to acquire a proper understanding and appreciation of the principles and technique involved. The relative non-existence of such books, however, does not mean that the subject is not being studied intensively and scientifically by at least some of those engaged in the building of rolling-mills. As Mr. Caswell, of course, is fully aware, the modern rolling-mill, particularly the cold-rolling mill has, of necessity, to be a first-class precision machine tool capable of rolling material to a high degree of accuracy, so that a correspondingly high degree of precision is essential in its design and construction. The developments which have taken place over recent years have been made possible mainly because of the recognition of this fact.

There is, therefore, in the hands of mill builders a considerable volume of reasonably exact engineering and scientific knowledge concerned with mill stands and their ancillary plant which has not yet been reduced to text-book form largely



XUM

because those best qualified to prepare a treatise on rolling-mills, analogous to those text-books existing in abundance on the other types of plant mentioned by Mr. Caswell, are too fully occupied with their own work to be able to spare the necessary time.

### *References*

1. A. NADAI : *Journal of Applied Mechanics, American Society of Mechanical Engineers*, 1939, June.
2. J. HITCHCOCK : *Rolling-Mill Journal*, 1931, vol. 5, September.
3. L. R. UNDERWOOD : *Sheet Metal Industries*, 1946, Oct., pp. 1901–1914.

Dr. **E. A. W. Hoff,** in reply to correspondence wrote : Mr. Caswell is perfectly right in pointing out that further investigations are required if more detailed conclusions are to be arrived at concerning the nature and cause of torque fluctuations between two driven rolls. If, however, only one roll is driven and receives the total torque, our method of recording cannot be expected to show up fluctuations of the type discussed in this paper. In the course of other experimental work, not at present under discussion, pure rolling torques had been, as a rule, determined from $T_1 - T_2$ in the same manner as proposed by Mr. Caswell, following a suggestion made by Dr. Orowan at the time.

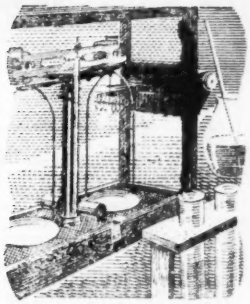
Mr. **W. Hessenberg** (The British Iron and Steel Research Association), in reply to the discussion on Siebel's Paper, wrote : The contribution of the Armament Research Department's Theoretical Research Group to the discussion on Dr. Siebel's paper reveals that a great advance has recently been made in the theory of plastic deformation. Until the details of this work are available for study it is hardly possible to do more than speculate upon the possibilities to which these new developments appear to lead. It is to be hoped that this interesting work will be given to the public at an early date.

One point of importance emerges from the discussion ; the new methods not only lead to more accurate solutions of the stress distribution in plastic deformation than were given by the older theories, but they give us the strain distribution as well. It is known that more work is required to effect a given change in shape in certain working processes such as rolling, drawing, etc., than by simple homogeneous deformation such as occurs in the earlier stages of the tensile test. The difference is composed of the work done against friction between the work and the tools and in effecting redundant strains which do not contribute to the net change of shape. The distinction between these two contributions to the extra work done has not always been made clear in the past. It should now be possible, by obtaining the strain distribution by these new methods, to estimate the redundant strain involved in a particular deformation process and distinguish between the frictional and redundant strain contributions to the extra work done. If this can be done it may eventually lead to beneficial changes in the shape and surface treatment of metal-working tools.

Dr. Balicki's comments remind us that there is a metallurgical side to these deformation problems ; existing theories of plastic deformation are complicated enough to tempt one to forget this for the time being. In hot working, however, work-hardening and re-softening may proceed together and at different rates ; this will have to be taken into account in any treatment of hot-working processes where it is necessary to know the value of yield stress at every stage. The results of the investigation which Dr. Balicki has been carrying out is therefore likely to be of considerable value in future studies of hot-working processes.

B. I. S. R. A.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION



# An Introduction to the Interaction of Carbon and Iron Ore at Temperatures up to 1450° C.*

*By H. L. Saunders, Ph.D., F.R.I.C.† and H. J. Tress, Ph.D.†*

SYNOPSIS

*The reduction of iron ore in the blast-furnace proceeds at all levels from the stack to the hearth, but the mechanism changes with increasing temperature. In the stack the reaction is " indirect," the CO of the reducing gas being converted to $CO_2$, whilst in the hearth the carbon reacts " directly " to give CO. Gaseous reduction diminishes as the porosity of the ore is reduced by the partial fusion of the gangue, the remaining oxygen being eliminated by reactions between ferrous oxide and various forms of carbon present at high temperatures. A number of comparative reduction rates have been determined for three ores and several types of carbon.*

DEFINITE equilibrium constants have been established[1-3] for the reduction of oxides of iron by blast-furnace gas at temperatures between 650° and 1000° C., showing that the reaction takes place in at least three stages :

(i) $Fe_2O_3 \rightarrow Fe_3O_4$ : 0–11% oxygen removal
(ii) $Fe_3O_4 \rightarrow FeO$ : 11–33% „ „
(iii) $FeO \rightarrow Fe$ : 33–100% „ „

The rate of deoxidation is very rapid for stage (i), which is irreversible at all measurable concentrations of carbon monoxide, and then diminishes through stage (ii) as the $Fe_3O_4$ suffers reduction. Although the fall continues again through stage (iii) there is often a nearly constant rate over the middle range of deoxidation, especially with Mesabi and Rubio ores. Eventually the rate becomes negligible at some limiting deoxidation depending on the temperature and nature of the ore, this limit being reached sooner with denser ores or those prone to low-temperature surface sintering. The limit varies from 75 to 90% over the temperature range 650–1000° C., and depends to some extent on the gas velocity (rate of driving).

In the blast-furnace, reduction by carbon proceeds simultaneously with reduction by gas, but, except where in intimate contact with the ore, the reaction is slight below 1000° C. It is only at higher temperatures in the removal of the last 10–25% of oxygen that reduction by carbon predominates. The $CO/CO_2$ ratio for the gaseous equilibrium increases very rapidly, especially where carburization occurs, and the reducing potential of the gas is thereby decreased. Carbon is present in the blast-furnace in various forms, *e.g.*, coke, carbon from the catalytic decomposition of carbon monoxide at lower temperatures, in combination with iron or other elements, and dissolved in the metal. All forms remove oxygen under suitable conditions, and it is the purpose of the present investigation to compare the rates of deoxidation with different types of ore and carbon.

## MATERIALS

Three ores, *A*, *B*, and *C*, of previous researches[1-5] were again employed ; the analyses of these ores are shown in Table I.

Each of the ores was about three-fourths reduced at 900° C. by carbon monoxide, with frequent reversals of gas flow, and then maintained in contact with circulating equilibrium

* Paper submitted by the Blast-Furnace Process Committee of the British Iron and Steel Research Association. Received 17th April, 1947. The views expressed are the authors', and are not necessarily endorsed by the Committee as a body.

† Imperial College of Science and Technology, South Kensington.



XUM

TABLE I—*Analyses of Ores used in the Investigations*

| Ore | $Fe_2O_3$, % | CaO, % | $SiO_2$, % | $Al_2O_3$, % | MnO, % | $CO_2$, % | $H_2O$ lost at 150°, % | $H_2O$ held at 150°, % |
|---|---|---|---|---|---|---|---|---|
| *A* (West Coast hematite) ... ... | 82·36 | 0·9 | 14·63 | 0·23 | Trace | ... | 0·6 | ... |
| *B* (Spanish Rubio) ... ... ... | 75·41 | Trace | 8·58 | 1·32 | ... | ... | 2·74 | 8·29 |
| *C* (Lincolnshire) ... ... ... | 31·95 | 32·5 | 4·75 | ... | 1·45 | 25·3 | 3·4 | ... |

gas for a sufficient time to ensure uniformity of composition, followed by cooling in nitrogen and subsequent thorough mixing. The deoxidation was calculated and later checked by chemical analysis, the final $\frac{1}{4}$–$\frac{1}{10}$-in. samples of *A*, *B*, and *C* being about 79, 68, and 81% reduced, respectively. Fully oxidized ore *A*, calcined in air at 650° C., was also used for some experiments below 1000° C.

The various forms of carbon were as follows :

(1) Carbon from the catalytic decomposition of carbon monoxide at 480° C.

(2) Durham coke : 60–100-in. mesh except where otherwise specified.

(3) Ceylon graphite : 100-mesh.

(4) Walloon pig (iron/carbon eutectic, 4·3% of carbon) showing nearly complete fusion at 1160° C. and liquefaction at 1180° C.

(5) Calcium carbide (76% $CaC_2$, with some free lime but no free carbon) : 10–40-mesh.

(6) Silicon carbide (no free carbon) : 200-mesh.

All the above materials were analysed for carbon content.

Before use the materials were separately degassed *in vacuo* at temperatures of up to 1100° C. (with the exception of Walloon pig which was just fused), but always below that of the experiment.

## APPARATUS

The reaction tube was heated by means of the carbon resistance furnace shown in Fig. 1. Current from the mains was fed *via* a 100-step auto-regulator to a transformer, the low voltage output being connected *via* the bus-bars *TT* to the water-cooled end plates *EE*. The carbon heater tube *CC* was held between pairs of tapering brass rings, *BB*, packed with carbon granules mixed with graphite. The bus-bars formed a trunnion mounting so that the furnace could be inclined to any suitable angle and locked by the wheels *WW*. The heater tube was surrounded by more granules as far as the graphite tube *AA*, which was packed with corundum to the ceramic cylinder *RR* and with magnesia asbestos packing to the casing. Possible points of air ingress were sealed with gasket cement to minimize oxidation of the heater. Accurate centring was essential when inserting a new tube, to avoid hot spots, and thorough cleaning of the clamping rings *BB* was desirable ; slackening the thumb-screws *SS* before cooling reduced unnecessary strain.

The general arrangement of the apparatus, as shown in Fig. 2, was designed to heat the material rapidly, so minimizing reaction below the experimental temperature. The reaction tube *P* of specially heat-treated Pythagoras, mullite, or alumina (*H*5 or *RR*, supplied by the Morgan Crucible Co.) rested on a carbon block, *C* ; this was supported on the lower mica-faced steel end plate in such a position that the charge was situated in the middle of the hot zone of the furnace. The charge was contained in an alumina crucible, *D*, hung on a tungsten-wire stirrup with a loop, as shown. A lifting hook was provided, operated from a vacuum-tight winder consisting of a flanged drum, *F*, fitting on the shank of a ground pyrex joint, *G*, and carrying a fine chain attached to the hook. The winding mechanism was located in the side arm of a Pyrex cap, the top being sealed with a fused-silica observation window, *Q*. The cap and window were fixed in position by sealing-wax, water-cooled where necessary, and thus the crucible could be rapidly lowered to its final position and an uninterrupted view of its contents obtained. A disappearing-filament pyrometer was sighted down the tube *P*, and when making observations a correction was applied for light absorption. The crucible was introduced or withdrawn through the ground-glass window joint. Connections were provided to other parts of the apparatus, lines to vacuum (1 and 2), manometers (3 and 6), standard-volume mercury gas pipette (4), inlet (5) for pure dried nitrogen (or argon when using silicon carbide or calcium carbide), and capacity bulb (7) for collecting the gaseous products of the reaction.

## PROCEDURE

The weights of material were calculated to give a particular carbon/reducible-oxygen atomic ratio (designated later as C/O ratio), and immediately before use the charge was dried *in vacuo* at 550° C. Meanwhile the refractory tube *P* was filled with nitrogen and stabilized at the experimental temperature. The silica window *Q* was removed and, whilst passing a slow stream of nitrogen, the suspended crucible was lowered into the tube, the hook engaged, and the window replaced and securely held by spring bands on the prongs *RR*.

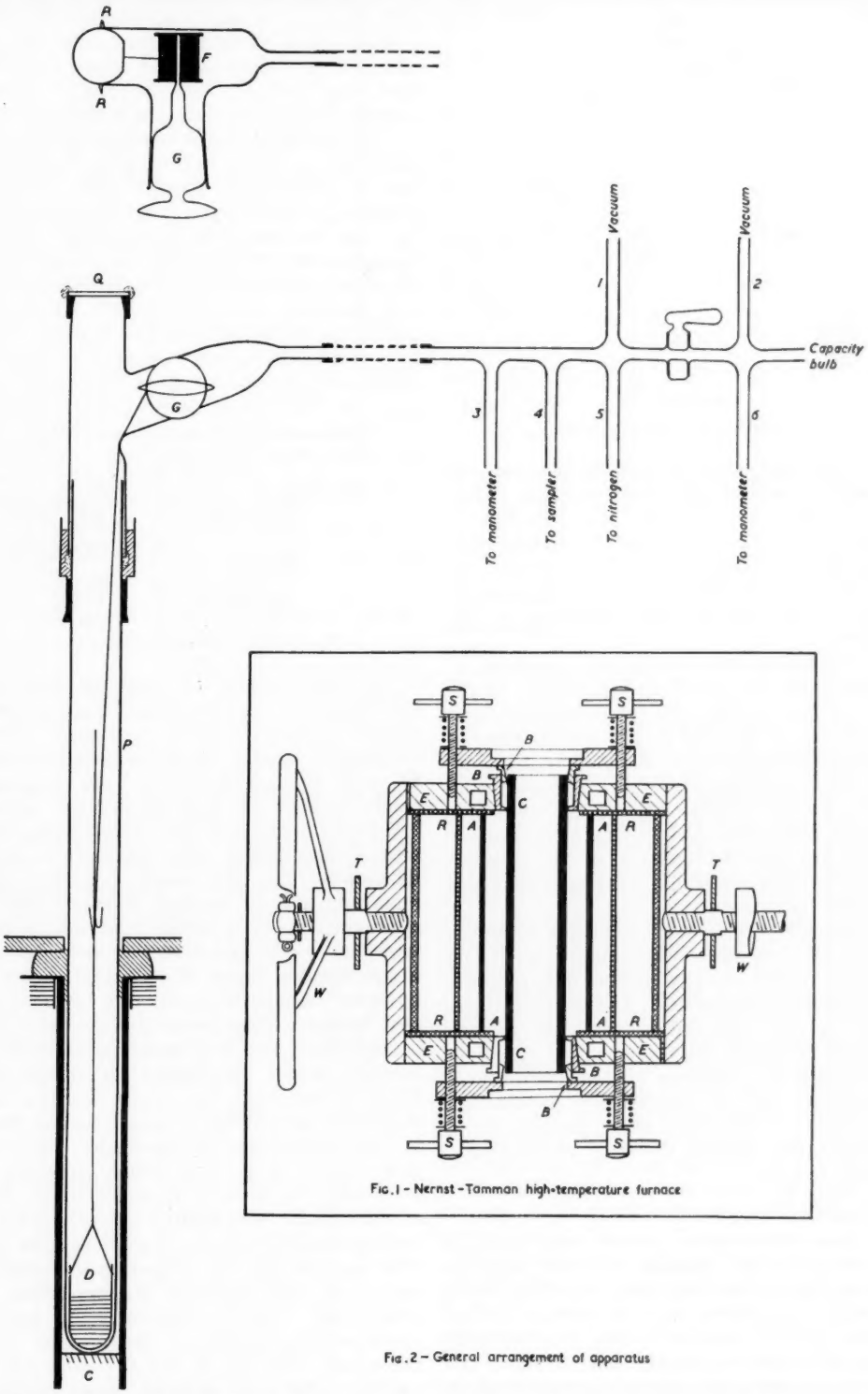



Fig. 1 – Nernst-Tamman high-temperature furnace

Fig. 2 – General arrangement of apparatus

FIGS. 1 and 2—Nernst-Tamman high-temperature furnace and general arrangement of apparatus

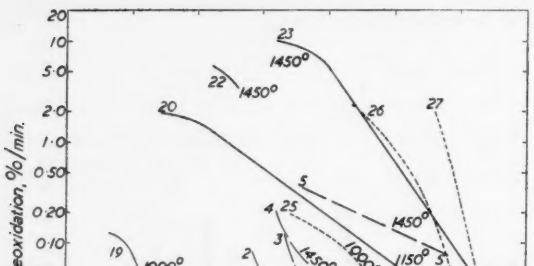



FIG. 3—Different ores and graphite

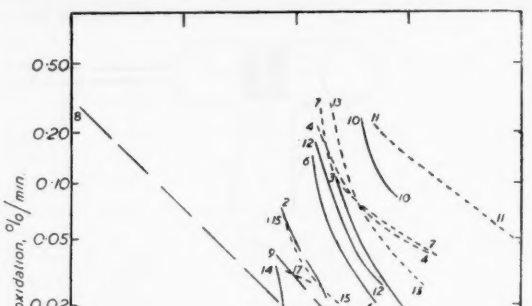
The crucible was raised as high as possible and the apparatus refilled twice with nitrogen; after a short interval the pressure was adjusted to atmospheric. Initial temperature stabilization and rapidity of manipulation were necessary to ensure that the nitrogen was under atmospheric pressure at the temperature conditions of the experiment.

The temperature was temporarily increased to compensate for the cooling due to the introduction of the crucible, which was next lowered to the bottom of the tube *P*. All gas in excess of atmospheric pressure was admitted to the previously exhausted capacity bulb, samples being collected in the pipette (4) at suitable time intervals for future analysis, giving (after deducting nitrogen) the composition of the gaseous products between sampling. True zero time was ascertained by extrapolation.

The volume of gas was calculated from the capacity-bulb pressures, due allowances being made for sampling and any changes in barometric pressure or gas temperature. The amount of gas evolved and its composition gave the oxygen removed from the ore, and this was plotted against time, as in Fig. 5. The slope of these curves gives the reduction rate as "percentage deoxidation per minute" which was then plotted on a logarithmic scale against the stage of reduction, as in Figs. 3 and 4.

## Comparative Results with Ores *A*, *B*, and *C*

The most reproducible results were obtained when using Ceylon graphite, as this material adheres to the ore particles and, on rolling, coats them with a continuous layer of carbon. A less intimate contact resulted when the requisite amount of carbon was merely sprinkled over the ore in the crucible, segregation being particularly marked with coke. There is indeed no wholly




| Curve | Temp., °C. | | Curve | Temp., °C. | |
|---|---|---|---|---|---|
| 2 | 1200 | Graphite | 10 | 1300 | Deposited carbon |
| 3 | 1300 | | 11 | 1450 | |
| 4 | 1450 | | 12 | 1300 | Walloon pig iron |
| 6 | 1300 | Coke | 13 | 1450 | |
| 7 | 1450 | | 14 | 1300 | SiC |
| 8 | 750 | Deposited carbon | 15 | 1450 | |
| 9 | 850 | | 17 | 1450 | $CaC_2$ |

FIG. 4—Ore *A* and different carbons

satisfactory method of ensuring that contact conditions can be standardized even at the start of an experiment and, moreover, they will continually change as the reduction progresses. In spite of this limitation the experimental results indicate the relative behaviour of the ores.

An examination of Fig. 3 will show that the rate of deoxidation falls rapidly at a particular temperature as the oxygen is progressively removed, and in several instances the curve approximates to a linear relationship between logarithmic rate and extent of deoxidation over a considerable range of reduction. A limit is, however, reached when the rate becomes so slow that further oxygen removal in a reasonable time is negligible. This is of consequence in the blast-furnace, where throughput times are roughly fixed by the character of the burden and the conditions of driving. Unused carbon remained at the termination of practically every experiment, apart from those where complete fusion occurred. An increase in the amount and rate of deoxidation was always observed with a rise in temperature, being most marked *circa* 1200° C. This may be seen by comparing the results with ore *A* at 850° (reaction inappreciable), 1200°, 1300°, and 1450° C. (curves 2, 3, and 4) at corresponding degrees of deoxidation, and also the results with ores *B* and *C* (curves 18–22 and 24–27). Ore *C* is reduced more quickly than ore *B*, and ore *A* is slowest. Here it is interesting

to note that this is the same order of reducibility as with blast-furnace gas[3] (*loc. cit.*, p. 45). The higher reduction rate maintained with ore *B* at deoxidations above 90% likewise shows a similar tendency. The increased reaction rate with excess of graphite is well illustrated by the relative position of curves 4 and 5 for ore *A* at 1450° C., and curves 22 and 23 for ore *B* at the same temperature. The difficulty of removing the last 10% of oxygen in ore *A* by the normal quantity of carbon, together with the increased rate and substantial extension of reduction with a doubled C/O ratio, may explain the high coke consumptions reported for blast-furnaces smelting this material. Ores *A* and *B* undergo an interesting series of changes during heating in contact with carbon. Up to 1000° C. there is little to distinguish them from similar material reduced by gas. Around 1150° C. surface sintering leads to cohesion; this is followed by semi-fusion of carburized products, which above 1200° C. commence to drain away, leaving particles of lime and silica relatively unaltered. The change is progressive above 1300° C., eventually resulting in separation of metal and gangue.

### Comparative Results with Different Types of Carbon

From Fig. 4 it will be seen that at all temperatures catalytic carbon is the most reactive, *e.g.*, at 750° C. (curve 8) rates of between 0·2 and 0·01% minimum were obtained when other varieties reacted so slowly that the values were inappreciable, even at a substantially higher temperature. At 850° C. the rate (curve 9) was nearly doubled, whilst it was necessary to raise the temperature as high as 1200° C. before similar rates were obtained with graphite or coke.

Both at 1300° and 1450° C. the reaction rates

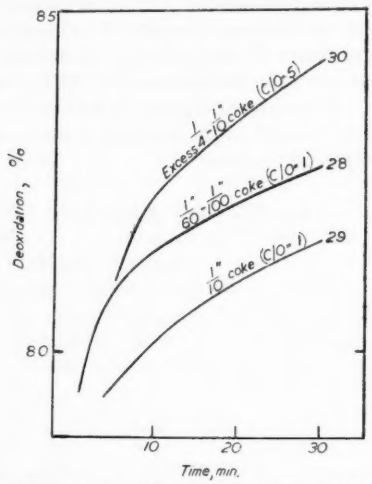



Fig. 5—Ore *A* and different-sized coke at 1300° C.

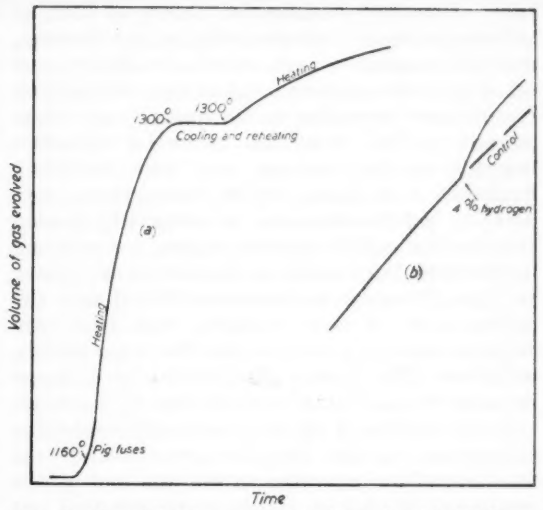



Fig. 6—Deoxidized ore *A*: (*a*) Heated with Walloon pig iron; (*b*) effect of hydrogen and deposited carbon at 850° C.

with 60–100-mesh coke (curves 6 and 7), Walloon pig (curves 12 and 13), and graphite (curves 3 and 4) are about the same, this in spite of the low carbon content of Walloon pig, while deposited carbon (curves 10 and 11) reacts several times faster at similar deoxidations. Over this temperature range a two-fold increase in respective rates was observed. Substitution of other forms by deposited carbon gave a higher rate than was obtained by raising the temperature by 150°.

Silicon carbide begins to react near 1300° C. (curve 14) but the rate is very slow indeed; at 1450° C. (curve 15), however, there is a substantial increase to a figure of the same order as with graphite at 1200° C. (curve 2), this value being also approached when using calcium carbide at 1450° C. (curve 17), though below this temperature the rate was negligible.

The effect of particle size is indicated in Fig. 5. These experiments were carried out at 1300° C., and deoxidation/time curves were drawn as before. Curves 29, 28, and 30 relate to 10-, 60–100-, and 4–10-mesh coke respectively, the standard ore size (4–10-mesh) being retained in each case. Starting with the same C/O ratio (unity) the rate increases as coke size is diminished. Commencing with a C/O ratio of 5 (*i.e.*, about the same bulk volumes of ore and coke) the rate was even greater, despite the use of larger (4–10-mesh) coke.

The reaction with Walloon pig is further illustrated by Fig. 6*a*, where the volume of gas evolved is plotted against time, using ¼–⅒ in., 75% reduced ore *A* with an initial C/O ratio of 0·8. The temperature was slowly raised. There was no reaction until liquefaction commenced near 1160° C. and was maintained with rising tempera-

ture. However, solidification occurs as soon as sufficient carbon is eliminated to induce freezing, and the reaction ceases. Such conditions may occur up to the melting point of iron, the freezing temperature depending on the quantity of carbon present. The reduction potential therefore depends on the amount of "near eutectic" available. At some higher temperature, *e.g.*, 1300° C., solidification can be induced by raising the crucible, and the reaction ceases, commencing again when the crucible is lowered to its former position. Reaction is always conditional upon the maintenance of new contacts, and this only happens when the melt reaches the same fluidity as before. The skeletal effect due to the drainage of carburized metal is shown in Fig. 7. Deoxidation by semi-fused pig iron assumes considerable importance in the blast-furnace. Fluidity is encouraged by impurities in the iron and by the continued solution of carbon to replace that lost in deoxidation.

The gaseous products of the reaction contained small amounts of hydrogen when coke was used, and it has been already shown that this gas catalyses both carbon deposition and gaseous deoxidation, besides itself performing a useful measure of reduction at all temperatures up to 850° C.,[5] especially when approaching $CO/CO_2$ equilibrium using highly reduced ores. Hydrogen is also a normal constituent of blast-furnace gas, and some experiments were therefore carried out where hydrogen was artificially introduced. A mixture of the evolved gas and twice its volume of nitrogen was circulated over a charge of 79% deoxidized ore *A* and deposited carbon (C/O = 1) at 850° C. On replacing 4% of the circulating gas by hydrogen there was an increase in gas generation, as shown in Fig. 6*b*, where the dotted line refers to a control experiment without hydrogen. This was due to acceleration of deoxidation by carbon, as deoxidation by hydrogen and carbon monoxide and the water-gas reaction occur without change of volume.

Two examples of reduction using a fully oxidized ore are mentioned which are of interest in connection with direct reduction processes.

In the first example, mixtures of through 60-mesh ore *A* and deposited carbon at 750° and 850° C. gave changes in the rate of deoxidation and in the $CO/CO_2$ ratio at about 11% and 33% deoxidation, pointing to reduction in the same stages ($Fe_2O_3 \rightarrow Fe_3O_4 \rightarrow FeO \rightarrow Fe$) as with blast-furnace gas. Increasing the temperature from 750° to 850° C., or the initial C/O ratio from 0·5 to 1, increased the rate and extent of deoxidation, but some unchanged carbon always remained. When deoxidation became very slow (*e.g.*, 75% deoxidation at 750° C. with a C/O ratio of 1) increased gas evolution was obtained by remixing the materials, *i.e.*, re-establishing contacts, or by increasing the temperature a further 100° C.

In the second example, powdered coal was substituted for deposited carbon. Table II gives results for a mixture of $\frac{1}{10}$–$\frac{1}{20}$-in. ore *A* and about a quarter of its weight of $\frac{1}{80}$–$\frac{1}{40}$-in. coal with an initial C/O ratio of 1. The deoxidation was performed under reduced pressure in three stages : The first at 650° C., the main reduction at 850° C., and the final at 950° C., the temperature being raised when the gas evolution had nearly ceased. Considerable oxygen was removed from the ore as water ; the hydrogen in the evolved gas diminished at each temperature, being about 40%, 15%, and 10%, respectively. Deoxidation to 75% was achieved at 850°, and to 90% at 950°, the rate diminishing gradually at each stage. After 56 hr. the $CO/CO_2$ ratio was rising rapidly and further reaction virtually ceased, though some unchanged carbon still remained.

## General Discussion of Results

It has been shown that carbon formed by the catalytic decomposition $2CO \rightarrow C + CO_2$ commences to reduce oxides of iron at temperatures as low as 650° and in fact may even be a more potent reducing agent at 750° C. than blast-furnace gas. This is well illustrated in previously recorded experiments[2] (*loc. cit.*, p. 50) where, under favourable conditions, the rate of oxygen removal was many times faster than by blast-furnace gas at similar ore deoxidations and $CO/CO_2$ ratios in the gas. With increasing deoxidation of the ore this effect became more marked even at a comparatively low temperature.

Table II—*Ore* A *and Coal*

| | Stage 1 | Stage 2 | Stage 3 |
|---|---|---|---|
| Temperature, ° C. ... | 650 | 850 | 950 |
| Pressure, atm. ... ... | 0·6 | 0·4 | 0·4 |
| Time, hr. ... ... | 1 | 42 | 56 |
| Deoxidation at end of stage, % ... ... | 2 | 75 | 90 |
| $CO/CO_2$ in evolved gas | 0·4 | 1·7–3·6 | 12–25 |
| Deoxidation, %/min. ... | ... | 0·015 at 68% | 0·007 at 88% |

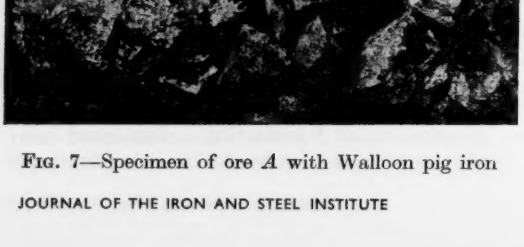


Fig. 7—Specimen of ore *A* with Walloon pig iron

Although at 750° C., under favourable conditions, carbon is capable of doing useful work as a reducing agent, it is unlikely to assume major industrial importance as a low-temperature direct reducing agent in competition with gaseous reduction without radical alteration in furnace design. It is certainly true that any increase in reaction temperature gives an increased rate of iron formation, but this is equally true of gaseous reduction, though even under the best conditions the progressive removal of oxygen, however performed, results in a very substantial diminution in the reaction velocity.

To make the best use of catalytic carbon demands an adequate yet carefully controlled impregnation of the ore without unduly choking the charge or weakening the matrix, as the latter must retain sufficient resistance to crushing and abrasion by the time it reaches the high-temperature zone of the furnace, or smooth operation would be difficult. Such finely divided carbon, however, could never be retained in large enough quantity under blast, unless contained within the interstices of the ore. Whilst it is true that with certain types of ore much larger quantities can be retained by the ore matrix without disintegration than by the hematites, these latter are usually the best catalysts for the carbon-deposition reaction. However, owing to their low porosity, much deposition around the iron nuclei as opposed to true impregnation necessarily occurs. A limited impregnation of high reactivity then results and the carbon is gasified at a comparatively early stage, when a corresponding oxygen removal could be effected equally well by carbon monoxide. Much depends upon the type of ore and its rate of passage through the intermediate (700–1000° C.) temperature zone. Externally deposited carbon is carried away by the blast to regions higher up in the furnace, where its presence in too great a quantity may be undesirable. This is the essential difference between impregnation and deposition.

Given a sufficiently rapid transit, enough carbon may be retained to perform much useful work before another close-contact reaction supervenes; for as the temperature rises above 1100° C. the interstices of the reduced ore become filled with near-eutectic material of relatively low melting point. This material provides a source of carbon in intimate contact with the remaining oxygen of the ore. This contact in the liquid state would seem conducive towards a higher reactivity, though there are necessarily two limitations imposed on the reactions involved. In the first place the solubility of carbon in iron is not very high (*e.g.*, the eutectic contains only 4·3% of carbon). Again, the melting point rises comparatively sharply below and above this value, and as this reaction occurs essentially in the liquid state the temperature factor is very important. Nevertheless, for similar quantities, carbon in solution is considerably more reactive than in its more usual form as lump coke.

Carbon as carbide is also a reducing agent whether it be combined with iron or other elements, such as calcium and silicon. Evidence of quite low-temperature formation of iron carbide has been obtained; it probably occurs concurrently with the carbon-deposition reactions in the 400–550° C. temperature range, though its extent depends on a number of factors such as the variation of $CO/CO_2$ ratio, temperature, and time of contact, and also on the nature of the iron-bearing materials, so that with different ores and different rates of driving this substance may be present in varying degree according to the preparation in the furnace stack. There is also the possibility of direct combination between carbon and iron. Very little information is available on the carbide present at various levels in the blast-furnace, and as the quantities do not seem to be high it is probable that synthesis and decomposition occur over a considerable range of conditions, the carbide being an intermediary in deoxidation.

It is important to keep in mind the location of the reacting carbon; this may be either internal or external to the iron oxides. Impregnated carbon, eutectic, and carbide provide examples of internal varieties, while deposited carbon and coke belong to the external types. With internal carbon there is little possibility of altering the degree of contact between the carbon and oxygen, but such a limitation is not necessarily imposed in the case of that situated externally. The quantity of the latter—or what is more important, the number of active contacts—can be increased by increasing the surface/weight ratio (decrease in particle size); by so doing a higher reaction rate would be anticipated, and this is confirmed by experiment (*see* curves 28, 29, 30, Fig. 5).

This question of contact becomes of increasing consequence at high temperatures, where reduction of the ore approaches completion; any increase in reduction velocity due to the temperature increment may be entirely offset by other changes, the nature of the ore becoming so altered by the partial fusion of slagging constituents in the gangue that it is rendered impervious to attack; reduction by gas then virtually ceases and coke reacts but slowly, yet carbon in the metal may still remove oxygen with little interference. In these experiments the C/O ratio generally employed was unity, and this corresponds with an approximate Fe/C ratio of 3, so that initially there was enough carbon to carburize all the iron present beyond the Fe/C eutectic. The final deoxidation in the blast-furnace



XUM

is greatly facilitated by excess of carbon.

In the penultimate stage much depends on the nature of the ore, and instances have been noted where eutectic material first coalesces and then drains away from the particles of ore in varying degree, leaving a porous matrix which is permeable to gas and continually exposes fresh surfaces.

In the final stage, when the bulk of the materials has been liquefied, it is only carbon dispersed in the liquid phase which can perform any useful oxygen removal at normal pressures, though the carbon monoxide so formed may still take up a little oxygen in its passage through the molten metal, since there is still a definite $CO/CO_2$ ratio dependent upon temperature in the fluid state.

Carbon monoxide is the main product of reduction by carbon, but below 1000° C. appreciable amounts of carbon dioxide are present, disappearing almost completely at higher temperatures; this indicates that the main course of the reaction can be represented as $FeO + C = Fe + CO$. Carbon dioxide results from reactions such as $2CO + 3Fe = Fe_3C + CO_2$, and $FeO + CO = Fe + CO_2$. The $CO/CO_2$ ratio always exceeds that for equilibrium blast-furnace gas in the absence of carburization, though it approaches this value when the gas-evolution rate is very slow. It will thus be seen that although at the commencement of an experiment the C/O ratio may have been fixed at unity, whenever carbon dioxide is formed more oxygen is removed than carbon, so that the later stages of reduction may take place under a more favourable C/O ratio; in spite of this, however, the rate of ore reduction invariably falls off with time. This fall is due not only to the removal of carbon and oxygen but also to a diminution in the number of contacts and the withdrawal of oxygen from the ore surface, giving a time lag while more oxygen diffuses from the interior.

For the guidance of blast-furnace technicians, the experimental results should primarily be regarded as indicative of comparative rates of oxygen removal under the experimental conditions specified, and are unsuitable for thermodynamical calculations. In the first place the ores—and to a lesser degree the forms of carbon—cannot be regarded as pure substances; moreover, the partial pressures in the gas phase were not externally controlled at every stage, and any subsequent reaction between the gas evolved and the solid was not minimized by working in a high vacuum.

According to the literature there is much difference of opinion as to the apportionment of such reactions as have herein been discussed between the solid state and by the intermediate agency of gas generated in the reaction. The comparative rates with ores *A*, *B*, and *C*, following their respective porosities, lends support to the predominance of a mechanism involving the gas phase.

In heterogeneous reactions of this nature the overall rate is limited by the slowest stage in the sequence which may vary with the conditions; both contact and diffusion play important rôles, as indicated by the small temperature coefficients which these reactions have in common with those of other heterogeneous reactions. Higher rates of reduction ensued when contact was improved by more thorough mixing, or even by remixing the charge in the course of an experiment. Compression and movement of the materials in the blast-furnace would have a similar effect.

## Summary

(1) The rates of reaction between partially reduced ores and various forms of carbon have been studied over a wide range of temperatures at varying deoxidations; rates of up to 10% deoxidation per minute have been observed.

(2) Oxygen removal was favoured not only by high temperature and low deoxidation, but also by increased C/O ratio and increase in contacts, *e.g.*, agitation and smaller particle size.

(3) Reduction rates fell markedly with increasing oxygen removal.

Under similar experimental conditions reaction rates decreased in the following sequence:

(*a*) Lincolnshire ore; Spanish Rubio; West Coast hematite.

(*b*) Catalytic carbon; small coke; graphite and molten Walloon pig iron; silicon carbide; calcium carbide.

(*c*) Carbon dissolved in molten iron; large coke.

(4) Carbon in intimate contact with the ore (as catalytic carbon, iron carbide, or near-eutectic) was particularly effective.

## Acknowledgments

The authors desire to acknowledge their indebtedness to Mr. R. P. Towndrow, M.Sc., for carrying out some of the earlier experiments before the work was interrupted by the outbreak of war. The experimental work embodied in this paper was carried out at the Imperial College of Science and Technology, South Kensington, and was financed by the British Iron and Steel Research Association.

## References

1. W. A. Bone, L. Reeve, and H. L. Saunders: *Journal of the Iron and Steel Institute*, 1927, No. I, pp. 127–166.
2. W. A. Bone, L. Reeve, and H. L. Saunders: *Ibid.*, 1930, No. I, pp. 35–81.
3. W. A. Bone, H. L. Saunders, and N. Calvert: *Ibid.*, 1934, No. I, pp. 33–46.
4. W. A. Bone, H. L. Saunders and J. E. Rushbrook: *Ibid.*, 1934, No. I, pp. 47–72.
5. W. A. Bone, H. L. Saunders, and H. J. Tress: *Ibid.*, 1938, No. I, pp. 85p–101p.

# Brittle Fracture in Mild-Steel Plates*

*By W. Barr, A.R.T.C., F.I.M.,† and Constance F. Tipper, M.A., D.Sc.‡*

SYNOPSIS

*The temperature range of transition from tough to brittle fracture of mild-steel plates of different carbon and manganese contents was determined by means of notched-bar impact, notched bend, and notched tensile tests. The results obtained by each of these tests were in good agreement, except that for very soft steels the notched tensile test gave a lower transition range than the other two tests.*

*It was found that the transition range is raised by an increase in the ferritic grain-size, by an increase in plate thickness, and by slow cooling after normalizing. It was also found that a high notched-bar impact value may be accompanied by a fracture which is mainly cleavage.*

*Tentative conclusions, subject to confirmation, have been reached that the effects of plate thickness and slow rates of cooling in raising the transition range are reduced in mild-steel plates with higher manganese contents.*

## INTRODUCTION

THE investigation of brittle fractures in steel is complicated by the many variables which have to be taken into consideration. In particular, as is well known, the size and shape of the notched test-piece and the manner of breaking have a pronounced influence on the nature of the fracture and on the energy absorbed. In general, the larger the test-piece and the faster the rate of loading the more prone is the steel to break with a brittle fracture and low energy absorption. However, it is reasonable to expect that steels of the same type, *i.e.*, of similar composition and tensile properties, would be placed in the same order of merit irrespective of test-piece size, as long as the same test-piece size is used in comparison. Another factor which must be taken into account in comparing the relative susceptibility of steels to brittle fracture is temperature. For every ferritic steel there is a temperature, or temperature range, below which in any given test the fracture obtained is almost entirely of the crystalline cleavage type. Depending on the steel and the dimensions of the test-piece, this temperature range may be very wide or very narrow. Therefore, this transition-temperature range, tough to brittle fracture, must be determined from the temperature/notched-bar curves.

The various forms of tests which have been used in investigating this problem include notched-bar impact tests, notched bend tests, and notched tensile tests, but as far as the authors are aware no attempt has been made to correlate the results obtained. It was, therefore, decided to compare the results obtained by these tests on a series of mild-steel plates. The notched-bar impact and the notched bend tests were carried out in the Colville laboratories, and the notched tensile tests were carried out in the Engineering Department of Cambridge University, under the direction of Professor J. F. Baker, O.B.E., Sc.D., M.A.

## SELECTION OF STEELS

Plates $\frac{1}{2}$ in., $\frac{3}{4}$ in., and 1 in. thick were selected from a normal production cast of steel to B.S.S.13 and Lloyds' requirements (26–32 tons/sq. in.). In a previous paper§ it was shown that manganese improves the impact value of mild steel and that steels of low manganese content were susceptible to slow rates of cooling. Accordingly, a production cast with higher manganese than normal was made, also to B.S.S.13, and $\frac{1}{2}$-in., $\frac{3}{4}$-in., and 1-in. plates were selected therefrom. A $\frac{3}{4}$-in. and a 1-in. plate of low-manganese steel of American origin, also intended to comply with B.S.S.13, and a $\frac{5}{8}$-in. thick plate of low-carbon, low-manganese steel, were selected in addition.

Tests were carried out on most of the steels in the as-rolled, normalized, and annealed conditions. The effects of water-quenching and of water-quenching and tempering were investigated on the low-manganese steels. Sulphur prints and deep-etch tests were made on the plate edges to ensure that the material was sound and uniform throughout.

Tests were also carried out on a riveted ship plate of continental origin which had fractured in service in an exceptionally brittle manner.

* Paper MG/5/46 of the Metallurgy (General) Division. Received 17th July, 1947. The views expressed are the authors' and are not necessarily endorsed by the Divisional Panel as a body.

† Messrs. Colvilles, Ltd., Glasgow.

‡ Formerly Miss C. F. Elam: Engineering Department, University of Cambridge.

§ Report of the Conference on "Brittle Fracture in Mild Steel Plates," held at Cambridge in October, 1945.

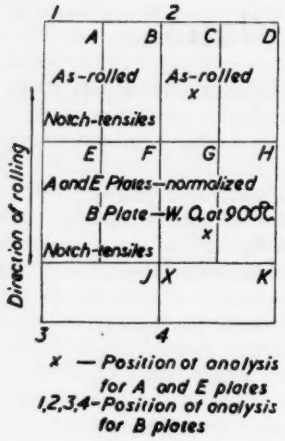



FIG. 1—Cutting diagrams for *A*, *E*, and *B* plates

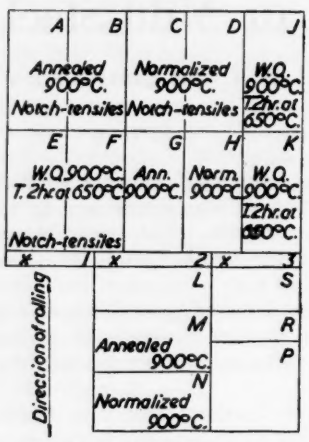



FIG. 2—Cutting diagram for plate *D*1

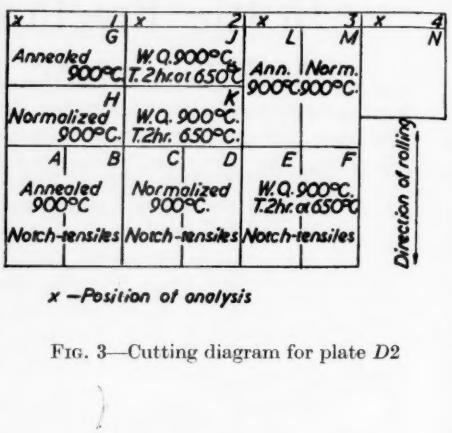



FIG. 3—Cutting diagram for plate *D*2

Nineteen different plate samples were subjected to all three methods of testing and this was found adequate for correlation purposes. A further eleven tests were carried out by the notched bend and/or impact methods to obtain additional data for examining the effect of heat-treatment and other variables.

## MATERIAL

### *Plates* A1, A2, *and* A3 *from Cast* K3904 *of Basic Open-Hearth Steel*

*Cast Analysis*

The analysis of cast *K*3904 was as follows :

| C, % | Si, % | S, % | P, % | Mn, % |
|---|---|---|---|---|
| 0·19 | 0·065 | 0·025 | 0·017 | 0·55 |

| Ni, % | Cr, % | Mo, % | Cu, % | Sn, % |
|---|---|---|---|---|
| 0·25 | 0·22 | 0·055 | 0·25 | 0·020 |

*Dimensions*

The dimensions of the ingot and plates were as follows :

7-ton ingot 38 in. × 19 in. at top, tapering to 41 in. × 22 in. at bottom.

Plate *A*1 ... ... 45 ft. × 55 in. × $\frac{1}{2}$ in.
Plate *A*2 ... ... 40 ft. × 56 in. × $\frac{3}{4}$ in.
Plate *A*3 ... ... 40 ft. × 57 in. × 1 in.

The test-pieces were cut from one end of each plate as shown in Fig. 1, and check analyses were taken on different portions, with the results shown in Table I.

The sulphur prints and deep-etch tests were normal. The A.S.T.M. (McQuaid-Ehn) grain-size of all three plates was 1–4.

### *Plates* E1, E2, *and* E3 *from Cast* J3904 *of Basic Open-Hearth Steel*

*Cast Analysis*

The analysis of cast *J*3904 was as follows :

| C, % | Si, % | S, % | P, % | Mn % |
|---|---|---|---|---|
| 0·15 | 0·070 | 0·032 | 0·015 | 0·99 |

*Dimensions*

The dimensions of the ingot and plates were as follows :

7-ton ingot 38 in. × 19 in. at top, tapering to 41 in. × 22 in. at bottom.

Plate *E*1 ... ... 38 ft. × 49 in. × $\frac{1}{2}$ in.
Plate *E*2 ... ... 38 ft. × 55 in. × $\frac{3}{4}$ in.
Plate *E*3 ... ... 25 ft. × 54 in. × 1 in.

The test-pieces were cut from one end of each

TABLE I—*Check Analyses for Plates* A1, A2, *and* A3

| Position of Test | C, % | Si, % | S, % | P, % | Mn, % | Ni, % | Cr, % | Mo, % | Cu, % | Sn, % | N, % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *A1C* | 0·185 | ... | 0·027 | ... | 0·55 | ... | ... | ... | ... | ... | ... |
| *A1G* | 0·18 | ... | ... | ... | 0·55 | ... | ... | ... | ... | ... | ... |
| *A1K* | 0·19 | 0·052 | 0·031 | 0·019 | 0·57 | 0·225 | 0·22 | 0·068 | 0·238 | 0·023 | 0·0045 |
| *A2C* | 0·195 | ... | 0·035 | ... | 0·58 | ... | ... | ... | ... | ... | ... |
| *A2G* | 0·20 | ... | ... | ... | 0·58 | ... | ... | ... | ... | ... | ... |
| *A2K* | 0·20 | 0·065 | 0·031 | 0·017 | 0·59 | 0·235 | 0·21 | 0·076 | 0·234 | 0·024 | ... |
| *A3C* | 0·23 | ... | 0·043 | ... | 0·57 | ... | ... | ... | ... | ... | ... |
| *A3G* | 0·235 | ... | ... | ... | 0·57 | ... | ... | ... | ... | ... | ... |
| *A3K* | 0·205 | 0·057 | 0·039 | 0·021 | 0·58 | 0·235 | 0·21 | 0·073 | 0·234 | 0·026 | ... |

TABLE II—*Check Analyses for Plates* E*1*, E*2, and* E*3*

| Position of Test | C, % | Si, % | S, % | P, % | Mn, % | Ni, % | Cr, % | Mo, % | Cu, % | Sn, % | N, % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *E1C* | 0·145 | 0·07 | 0·034 | 0·016 | 1·07 | 0·14 | 0·065 | 0·045 | 0·18 | 0·025 | 0·0047 |
| *E1G* | 0·15 | ... | 0·029 | ... | 1·06 | ... | ... | ... | ... | ... | ... |
| *E1K* | 0·145 | ... | 0·028 | ... | 1·07 | ... | ... | ... | ... | ... | ... |
| *E2C* | 0·145 | 0·10 | 0·031 | 0·017 | 1·04 | 0·18 | 0·07 | 0·06 | 0·15 | 0·022 | ... |
| *E2G* | 0·155 | ... | 0·029 | ... | 1·06 | ... | ... | ... | ... | ... | ... |
| *E2K* | 0·145 | ... | 0·028 | ... | 1·04 | ... | ... | ... | ... | ... | ... |
| *E3C* | 0·145 | 0·07 | 0·034 | 0·017 | 1·05 | 0·13 | 0·06 | 0·05 | 0·185 | 0·024 | ... |
| *E3G* | 0·165 | ... | 0·035 | ... | 1·06 | ... | ... | ... | ... | ... | ... |
| *E3K* | 0·155 | ... | 0·034 | ... | 1·06 | ... | ... | ... | ... | ... | ... |

plate as shown in Fig. 1, and check analyses were taken on different portions, with the results shown in Table II.

The sulphur prints and deep-etch tests were normal. The A.S.T.M. (McQuaid-Ehn) grain-size of all three plates was 1–4.

*Plates* D*1 and* D*2 of American Basic Open-Hearth Steel*

The details of manufacture of plates *D*1 and *D*2 are not known. The test-pieces were cut from the end of each plate as shown in Figs. 2 and 3.

*Dimensions*

The dimensions of the plates were as follows :

Plate *D*1 ... ... 16 ft. × 5 ft. × $\frac{3}{4}$ in.
Plate *D*2 ... ... 20 ft. × 8 ft. × 1 in.

Analyses made at different positions gave the results shown in Table III.

The sulphur prints and deep-etch tests were normal. The A.S.T.M. (McQuaid-Ehn) grain-size for plate *D*1 was 4–7 and for plate *D*2, 2–3.

*Plate* B *from Cast* T*377 of Acid Open-Hearth Steel*

*Cast Analysis*

The analysis of cast *T*337 was as follows :

| C, % | Si, % | S, % | P, % | Mn, % |
|---|---|---|---|---|
| 0·09 | 0·07 | 0·037 | 0·040 | 0·50 |

*Dimensions*

The dimensions of the ingot and plate were as follows :

11-ton ingot 54$\frac{1}{4}$ in. × 21$\frac{3}{4}$ in. at top, tapering to 57$\frac{1}{4}$ in. × 24$\frac{3}{4}$ in. at bottom
Rolled size 15 ft. × 51 in. × $\frac{5}{8}$ in.

The test-pieces were cut from one end of the plate as shown in Fig. 1, and check analyses were taken on different portions, with the results shown in Table IV.

The sulphur prints and deep-etch tests were normal. The A.S.T.M. (McQuaid-Ehn) grain-size was 1–4.

*Plate* Z *from the s.s.* Bornholm

Plate *Z* was a 10-mm. thick riveted lower-deck

TABLE III—*Analyses for Plates* D*1 and* D*2*

| Position of Test | C, % | Si, % | S, % | P, % | Mn, % | Ni, % | Cr, % | Mo, % | Cu, % | Sn, % | N, % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *D*1–1 | 0·24 | ... | 0·026 | ... | 0·34 | ... | ... | ... | ... | ... | ... |
| *D*1–2 | 0·23 | 0·04 | 0·024 | 0·010 | 0·34 | Nil | 0·025 | 0·02 | 0·01 | Trace | 0·0057 |
| *D*1–3 | 0·22 | ... | 0·032 | ... | 0·34 | ... | ... | ... | ... | ... | ... |
| *D*2–1 | 0·20 | ... | 0·013 | ... | 0·39 | ... | ... | ... | ... | ... | ... |
| *D*2–2 | 0·235 | Trace | 0·020 | 0·010 | 0·41 | 0·09 | 0·03 | 0·04 | 0·17 | 0·021 | 0·0040 |
| *D*2–3 | 0·23 | ... | 0·019 | ... | 0·40 | ... | ... | ... | ... | ... | ... |
| *D*2–4 | 0·225 | ... | 0·023 | ... | 0·39 | ... | ... | ... | ... | ... | ... |

TABLE IV—*Check Analyses for Plate* B

| Position of Test | C, % | Si, % | S, % | P, % | Mn, % | Ni, % | Cr, % | Mo, % | Cu, % | Sn, % | N, % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *B*1 | 0·095 | 0·07 | 0·035 | 0·035 | 0·50 | 0·11 | 0·03 | 0·04 | 0·115 | 0·013 | 0·0041 |
| *B*2 | 0·085 | ... | 0·028 | ... | 0·50 | ... | ... | ... | ... | ... | ... |
| *B*3 | 0·085 | ... | 0·029 | ... | 0·50 | ... | ... | ... | ... | ... | ... |
| *B*4 | 0·095 | ... | 0·032 | ... | 0·49 | ... | ... | ... | ... | ... | ... |

TABLE V—*Analyses for Plate Z*

| Position of Test | C, % | Si, % | S, % | P, % | Mn, % | Ni, % | Cr, % | Mo, % | Cu, % | Sn, % | N, % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *C* | 0·12 | Trace | 0·038 | 0·061 | 0·45 | 0·04 | 0·02 | 0·04 | 0·065 | 0·010 | 0·024 |
| *D* | 0·135 | ... | ... | ... | 0·45 | ... | ... | ... | ... | ... | ... |
| *K* | 0·135 | ... | ... | ... | 0·45 | ... | ... | ... | ... | ... | 0·019 |

floor plate from the Danish ship *Bornholm*. A sketch of the plate is shown in Fig. 59, from which it will be noted that the plate has fractured and cracked extensively. These failures were accompanied by no deformation of the plate. At one portion marked *P* a crack had been repaired by welding. None of the other plates in the vicinity of this one showed any evidence of cracking.

Test-pieces were cut from the plate as shown in Fig. 59. Analyses taken at different portions gave the results shown in Table V.

Sulphur prints showed the plate to be of rimming quality. The A.S.T.M. (McQuaid-Ehn) grain-size was 1–3.

### MICROSTRUCTURE AND CLEANNESS

Length and cross-sections for micro-examination were cut from each plate. The results will be considered when necessary with the results of the temperature/fracture tests.

### MECHANICAL PROPERTIES

Length and cross test-pieces were taken from each plate and the mechanical properties obtained are shown in Table VI.

### TEMPERATURE/FRACTURE TESTS

#### *Notched-Bar Impact Test*

The notched-bar test-pieces were 10 mm. square by 56 mm. long and were notched with the standard Izod notch. For these notches and all other standard notches, milling cutters tested at Cambridge University were specially reserved. The test-pieces were broken in the standard 30-kg. Charpy impact machine, the striking energy being 169 ft. lb. All notches were cut at right angles to the plate surface. This notched-bar impact test gives values tending to be slightly lower than, but approximately equal to, those from the Izod test.

For tests above room temperature, the test-pieces were immersed in water and maintained at the required temperature for 10 min. They were then quickly transferred to the testing machine and broken within a maximum period of 5 sec. For temperatures below 10° C. the specimens were cooled by immersion in a mixture of drikold and ether for a period of 10 min., transferred to the testing machine, and broken within 5 sec. In carrying out the test both the energy absorbed in fracturing and the relative amounts of cleavage and of fibrous fracture obtained were recorded. A comparison of this impact test with the Hounsfield impact test was carried out (*see* Fig. 4) on one of the plates, *A*2, the results of which will be referred to later.

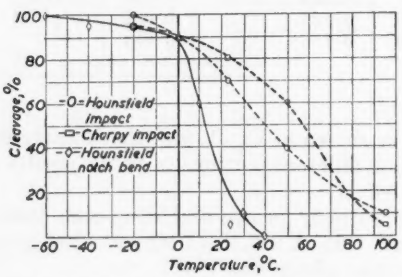



FIG. 4—Comparison of Hounsfield impact, Charpy impact, and Hounsfield notched bend tests on plate *A*2, as rolled

#### *Notched Tensile Tests*

The method of carrying out notched tensile tests has been described in previous reports.* The full thickness of plate was used and the test-pieces were all 1 in. wide. Although the temperature was not kept constant by immersing the specimen in a bath, a thermocouple was attached while the test was being carried out, so that the exact temperatures at yield and fracture are known. All notches were cut at right angles to the plate surface.

#### *Notched Bend Tests*

From a consideration of the various factors involved, it was thought that the determination of the relative amount of cleavage and of fibrous fracture in a simple form of notched bend test involving the full thickness of the plate would provide a useful practical method for estimating the temperature range of transition from tough to brittle fracture (hereafter called the transition range). A series of preliminary test-pieces was therefore cut from the $\frac{3}{4}$-in. thick plate, *A*2, having widths of 1 in. and $1\frac{1}{2}$ in., with a standard Izod notch cut across the thickness of each plate. Tests were carried out at various temperatures in order to determine the transition range, the temperature

* Report to D.S.R., Admiralty, 1944, FE.4/142. Also Report of Cambridge Conference, 1945.

TABLE VI—*Mechanical Tests at* 18° *C.*

| Specimen | Thickness, in. | Treatment | Direction of Tests | Maximum Stress, tons/sq. in. | Yield Point, tons/sq. in. | Elongation, % on 8 in. | Reduction of Area, % | Izod Value, ft. lb. |
|---|---|---|---|---|---|---|---|---|
| *A*1 | ½ | A.R.* | L | 30·4 | 18·5 | 25 | 57 | 54 |
| | | | X | 30·2 | 19·6 | 25 | 46 | 28 |
| *A*2 | ¾ | A.R. | L | 31·4 | 18·8 | 23 | 56 | 37 |
| | | | X | 30·8 | 18·7 | 23 | 44 | 28 |
| *A*3 | 1 | A.R. | L | 32·1 | 17·2 | 22 | 55 | 27 |
| | | | X | 32·4 | 17·0 | 22 | 42 | 24 |
| *A*1 | ½ | N. 900° C. | L | 31·0 | 17·2 | 24 | 50 | 57 |
| | | | X | 30·4 | 17·0 | 22 | 44 | 32 |
| *A*1 | ½ | N. 850° C. | L | 29·4 | 17·8 | 24 | 55 | 59 |
| *A*1 | ½ | N. 900° C. +A. 900° C. | L | 26·8 | 16·8 | 26 | 52 | 43 |
| *A*2 | ¾ | N. 900° C. | L | 30·8 | 17·0 | 25 | 56 | 48 |
| | | | X | 30·3 | 17·5 | 25 | 51 | 32 |
| *A*2 | ¾ | N. 850° C. | L | 30·5 | 19·8 | 26 | 49 | 55 |
| | | | X | 30·7 | 19·9 | 26 | 54 | 37 |
| *A*3 | 1 | N. 900° C. | L | 31·4 | 16·0 | 24 | 52 | 27 |
| | | | X | 31·2 | 15·6 | 24 | 49 | 24 |
| *A*3 | 1 | N. 850° C. | L | 31·0 | 16·9 | 25 | 55 | 36 |
| | | | X | 30·7 | 16·5 | 24 | 52 | 26 |
| *E*1 | ½ | A.R. | L | 30·8 | 19·2 | 23 | 58 | 81 |
| | | | X | 30·2 | 19·2 | 25 | 57 | 54 |
| *E*2 | ¾ | A.R. | L | 29·2 | 15·3 | 28 | 60 | 67 |
| | | | X | 30·0 | 16·8 | 29 | 55 | 43 |
| *E*3 | 1 | A.R. | L | 29·5 | 16·3 | 30 | 64 | 72 |
| | | | X | 29·3 | 16·5 | 28 | 65 | 50 |
| *E*1 | ½ | N. 850° C. | L | 30·0 | 19·0 | 24 | 59 | 82 |
| *E*1 | ½ | N. 900° C. +A. 900° C. | L | 27·1 | 17·7 | 24 | 58 | 65 |
| *E*2 | ¾ | N. 850° C. | L | 29·1 | 18·0 | 31 | 62 | 71 |
| | | | X | 29·4 | 17·8 | 27 | 58 | 44 |
| *E*2 | 1 | N. 850° C. | L | 28·9 | 17·4 | 28 | 63 | 82 |
| | | | X | 29·1 | 17·2 | 25 | 57 | 48 |
| *D*1 | ¾ | A. 900° C. | L | 23·4 | 14·8 | 32 | 63 | 9 |
| | | | X | 23·2 | 13·7 | 30 | 58 | 8 |
| *D*2 | 1 | A. 900° C. | L | 24·5 | 12·7 | 32 | 58 | 8 |
| | | | X | 24·0 | 13·1 | 31 | 50 | 8 |
| *D*1 | ¾ | N. 900° C. | L | 26·6 | 16·4 | 31 | 62 | 59 |
| | | | X | 26·3 | 16·8 | 29 | 51 | 43 |
| *D*2 | 1 | N. 900° C. | L | 26·7 | 14·8 | 29 | 54 | 31 |
| | | | X | 26·8 | 15·4 | 31 | 55 | 32 |
| *D*1 | ¾ | W.Q. 900° C. T. 2 hr. 600° C. | L | 30·5 | 22·0 | 26 | 62 | 73 |
| | | | X | 29·2 | 22·3 | 23 | 58 | 52 |
| *D*2 | 1 | W.Q. 900° C. T. 2 hr. 650° C. | L | 30·6 | 21·2 | 25 | 62 | 58 |
| | | | X | 30·0 | 22·5 | 21 | 57 | 47 |
| *B* | ⅝ | A.R. | L | 24·9 | 15·1 | 33 | 55 | 38 |
| | | | X | 24·7 | 14·6 | 31 | 54 | 42 |
| *B* | ⅝ | N. 900° C. +A. 900° C. | L | 21·3 | 13·1 | 36 | 59 | 25 |
| *B* | ⅝ | W.Q. 900° C. | L | 30·8 | 22·7 | 22 | 55 | 39 |
| | | | X | 31·0 | 21·4 | 22 | 56 | 42 |
| *Z* (*c*) | 10 mm. | As received | L | 27·2 | 17·0 | 20 | 59 | 12 |
| | | | X | 27·6 | 17·8 | 19 | 57 | 9 |

* A.R. = As rolled

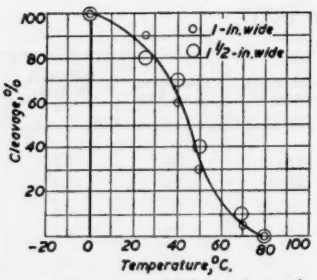



FIG. 5—Comparison of notched-bend results for specimens 1 in. and 1½ in. wide of plate *A*2, as rolled

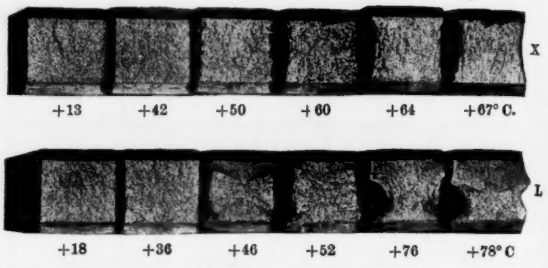



FIG. 6—Fractures of notched tensile test-pieces of plate *A*3 (figures indicate temperature at fracture in °C.)

in all cases being obtained in the same manner as for the impact test described above. Similar results were obtained in both cases (*see* Fig. 5), from which it may be concluded that the width of the test-piece within these limits was not critical. It was subsequently found that practically the same results were obtained by a saw-cut notch and the test-piece was standardized at 1 in. wide, with a saw-cut approximately $\frac{3}{16}$ in. deep across the full thickness of the plate. The test-pieces were broken by steam pressure against rollers 8 in. between centres, the notch, of course, being on the tension side. The duration of the test from the commencement of bending to fracture was approximately 2–3 sec. It was necessary to make a small predetermined allowance for temperature drop during transfer from the liquid bath to the testing apparatus. The temperature drop was measured by inserting a thermometer in a test-piece and noting the drop in temperature at the time of commencement of bend. This temperature drop never exceeded 3° C. The percentage of cleavage in the various fractures was estimated by visual examination.

## EXPERIMENTAL RESULTS

### *Notched Tensile Tests*

Table VII gives the numerical values of yield and ultimate stress, elongation, and nature of fracture at the different temperatures. These results were plotted and the point halfway between two tests where a change of fracture has occurred was taken as a limit of the transition range. The accuracy in determining these limits depends partly on the number of test-pieces available and partly on the width of the range. The areas of fibrous and cleavage fracture which were obtained within the transition range were measured on a Hilger projector in a few instances ; otherwise, the fractures are classified as partly fibrous, partly cleavage, without figures being given. The method of determining the transition range by examination of the fractures is similar to that used in notched bend and impact tests. Two typical series of broken test-pieces are shown in Fig. 6.

The temperatures at fracture of the transition ranges are given in Table VIII. Included in this table are the results obtained by the measurement of the cleavage areas in notched bend and impact tests. Actual grain-size counts and Vickers hardness numbers are also given. In making the counts, ferrite and pearlite areas were counted separately. The total number of grains, including pearlite, depends to some extent on the carbon content. No attempt was made to estimate the grain-size of the plates *D*1 and *D*2 in the quenched condition.

TABLE VII—*Notched Tensile Tests**

| Temp. at Yield, °C. | Temp. at Ultimate Stress, °C. | Yield Stress, tons/sq. in. | Ultimate Stress, tons/sq. in. | Elongation on 2 in., % | Direction of Rolling | Crystalline Area in Fracture, % |
|---|---|---|---|---|---|---|
| | | | *Colville A1* | | | |
| *As rolled*, t = *0·517* in. | | | | | | |
| +16 | +16 | 16·6 | 31·1 | 9·5 | L | 0 |
| 0 | + 3 | 17·2 | 33·9 | 11·5 | L | 0 |
| − 1 | + 1 | 17·0 | 33·9 | 11·5 | L | 12·5 |
| −10 | − 5 | 17·9 | 34·0 | 10·0 | L | 38 |
| −12 | − 8 | 17·6 | 34·9 | 10·0 | L | 74 |
| −14 | −10 | 17·4 | 34·0 | 10·0 | L | 40·5 |
| −22 | −18 | 18·4 | 34·2 | 10·5 | L | 37·5 |
| −23 | −18 | 17·9 | 34·9 | 7·5 | L | 85 |
| −26 | −21 | 16·8 | 34·2 | 8·0 | L | 83 |
| −39 | −36 | 19·8? | 34·0 | 5·5 | L | 94·5 |
| *Machined*, t = *0·453 in.* | | | | | | |
| +19 | +20 | 15·9 | 33·3 | 10·5 | L | Fib. |
| − 2 | 0 | 17·8 | 32·4 | 10·5 | L | Fib. |
| − 9 | − 5 | 17·9 | 34·4 | 10·5 | L | Fib./patch cryst. |
| −10 | − 1 | 18·3 | 36·0 | 6·5 | L | Cryst. |
| −12 | − 8 | 17·5 | 34·5 | 11·0 | L | Cryst./fib. |
| −14 | −10 | 18·0 | 35·1 | 6·5 | L | Cryst. |
| −23 | −18 | 18·0 | 35·4 | 7·0 | L | Cryst. |
| −23 | −19 | 18·7 | 35·4 | 6·0 | L | Cryst. |
| *As rolled*, t = *0·517 in.* | | | | | | |
| +12 | +12 | 16·7 | 29·2 | 7·0 | X | Fib. |
| − 4 | − 3 | 16·4 | 30·0 | 7·0 | X | Fib./patch cryst. |
| −13 | −11 | 17·3 | 30·8 | 7·0 | X | Cryst./fib. |
| −22 | −19 | 17·9 | 31·0 | 6·5 | X | Cryst./fib. |
| −25 | −22 | 17·5 | 31·1 | 6·0 | X | Cryst./fib. |
| −32 | −29 | 18·4 | 31·4 | 5·5 | X | Cryst. |
| *Machined*, t = *0·455 in.* | | | | | | |
| + 8 | + 9 | 17·6 | 29·2 | 6·0 | X | Fib. |
| − 2 | 0 | 18·7 | 30·1 | 6·0 | X | Fib./patch cryst. |
| −13 | −11 | 17·9 | 30·2 | 6·0 | X | Cryst./fib. |
| −22 | −19 | 17·5 | 30·6 | 6 0 | X | Cryst./fib. |
| −31 | −29 | 17·9 | 30·0 | 5·5 | X | Cryst./fib. |
| −46 | −45 | 19·7 | 31·3 | 3·5 | X | Cryst. |
| *Normalized from 900° C.*, t = *0·520 in.* | | | | | | |
| + 1 | + 5 | 17·0 | 33·2 | 12·0 | L | Fib. |
| −15 | − 9 | 16·9 | 34·2 | 11·0 | L | Fib./patch cryst. |
| −22 | −17 | 18·3 | 34·7 | 11·5 | L | Cryst./fib. |
| −23 | −17 | 18·7 | 34·5 | 11·0 | L | Cryst./fib. |
| −26 | −20 | 18·7 | 34·4 | 7·5 | L | Cryst. |
| −30 | −26 | 19·7 | 35·5 | 7·5 | L | Cryst. |

* All specimens 1 in. wide, double-notched $\frac{1}{4}$ in., 45°, $t$ = thickness of plate.

## TABLE VII (*contd.*)—*Notch Tensile Test**

| Temp. at Yield, °C. | Temp. at Ultimate Stress, °C. | Yield Stress, tons/sq. in. | Ultimate Stress, tons/sq. in. | Elongation on 2 in., % | Direction of Rolling | Crystalline Area in Fracture, % |
|---|---|---|---|---|---|---|
| | | | *Colville* A2 | | | |
| *As rolled*, t = 0·737 *in.* | | | | | | |
| +66 | +66 | 14·5 | 32·2 | 12·0 | L | Fib. |
| +47 | +47 | 16·1 | 33·5 | 11·5 | L | Cryst./fib. |
| +41 | +41 | 14·6 | 33·4 | 12·0 | L | Cryst./fib. |
| +26 | +27 | 16·3 | 33·5 | 11·5 | L | Cryst./fib. |
| +19 | +21 | 15·4 | 34·4 | 9·0 | L | Cryst. |
| +16 | +18 | 14·9 | 33·5 | 10·5 | L | Cryst. |
| *Machined*, t = 0·4365 *in.* | | | | | | |
| +41 | +41 | 15·1 | 34·2 | 9·5 | L | Fib. |
| +36 | +37 | 15·9 | 34·3 | 11·0 | L | Fib. |
| +30 | +30 | 14·9 | 34·4 | 7·0 | L | Cryst. |
| +19 | +21 | 15·9 | 34·5 | 8·5 | L | Cryst. |
| *As rolled*, t = 0·737 *in.* | | | | | | |
| +61 | +60 | 14·2 | 30·4 | 9·0 | X | Fib. |
| +53 | +52 | 14·9 | 30·8 | 9·5 | X | Fib./patch cryst. |
| +48 | +46 | 14·7 | 30·4 | 8·5 | X | Cryst./fib. |
| +38 | +38 | 15·5 | 31·0 | 8·5 | X | Cryst./fib. |
| +31 | +31 | 14·9 | 31·2 | 7·5 | X | Cryst./fib. |
| +13 | +14 | 15·5 | 31·5 | 7·0 | X | Cryst. |
| *Machined*, t = 0·454 *in.* | | | | | | |
| +36 | +35 | 16·1 | 30·1 | 7·0 | X | Fib./patch cryst. |
| +26 | +26 | 15·5 | 30·9 | 8·0 | X | Fib./patch cryst. |
| +21 | +21 | 15·9 | 31·3 | 8·0 | X | Cryst./fib. |
| +20 | +20 | 15·4 | 30·5 | 8·0 | X | Cryst./fib. |
| +16 | +17 | 15·1 | 31·1 | 7·0 | X | Cryst./fib. |
| +13 | +14 | 15·8 | 31·8 | 4·0 | X | Cryst. |
| *Normalized from 900° C.*, t = 0·740 *in.* | | | | | | |
| +34 | +35 | 16·4 | 33·1 | 13·0 | L | Fib./patch cryst. |
| +29 | +29 | 16·3 | 33·4 | 12·5 | L | Fib./patch cryst. |
| +20 | +22 | 16·5 | 33·8 | 11·5 | L | Cryst./fib. |
| + 8 | +12 | 18·1 | 34·3 | 12·0 | L | Cryst./fib. |
| − 2 | + 3 | 17·0 | 35·0 | 8·5 | L | Cryst. |
| | | | *Colville* A3 | | | |
| *As rolled*, t = 0·969 *in.* | | | | | | |
| +73 | +76 | 14·1 | 32·4 | 13·5 | L | 5·5 |
| +69 | +78 | 14·1 | 31·8 | 12·5 | L | 13 |
| +52 | +52 | 15·0 | 33·4 | 11·5 | L | 48 |
| +44 | +46 | 14·0 | 33·2 | 12·0 | L | 42 |
| +36 | +36 | 16·7 | 29·0 | 3·5 | L | 96 |
| +17 | +18 | 14·8 | 33·0 | 6·0 | L | 95·5 |
| *Machined*, t = 0·4335 *in.* | | | | | | |
| +40 | +40 | 16·6 | 33·7 | 8·0 | L | Fib./patch cryst. |
| +35 | +35 | 17·1 | 34·6 | 5·0 | L | Cryst. |
| +32 | +32 | 16·2 | 35·0 | 5·5 | L | Cryst. |
| +19 | +20 | 17·7 | 34·2 | 4·0 | L | Cryst. |
| *As rolled*, t = 0·973 *in.* | | | | | | |
| +67 | +67 | 16·7 | 32·3 | 8·0 | X | Fib. |
| +65 | +64 | 16·1 | 30·9 | 9·0 | X | Cryst./fib. |
| +61 | +60 | 15·3 | 31·4 | 9·0 | X | Cryst./fib. |
| +51 | +50 | 16·4 | 31·9 | 7·0 | X | Cryst./fib. |
| +42 | +42 | 16·7 | 32·4 | 5·0 | X | Cryst. |
| +13 | +13 | 15·9 | 30·8 | ... | X | Cryst. |
| *Machined*, t = 0·452 *in.* | | | | | | |
| +49 | +48 | 16·7 | 32·1 | 7·0 | X | Fib. |
| +43 | +42 | 15·8 | 32·1 | 6·0 | X | Cryst./fib. |
| +40 | +39 | 18·3 | 33·4 | 5·5 | X | Cryst./fib. |
| +36 | +36 | 17·4 | 31·6 | 6·5 | X | Cryst./fib. |
| +32 | +31 | 16·5 | 32·4 | 4·0 | X | Cryst. |
| +14 | +14 | 17·3 | 31·2 | 2·5 | X | Cryst. |
| *Normalized from 900° C.*, t = 0·979 *in.* | | | | | | |
| +77 | +77 | 16·0 | 32·5 | 13·0 | L | Fib. |
| +67 | +66 | 16·1 | 32·5 | 12·5 | L | Cryst./fib. |
| +53 | +51 | 15·9 | 33·0 | 12·0 | L | Cryst./fib. |
| +40 | +41 | 16·6 | 33·6 | 10·5 | L | Cryst./fib. |
| +32 | +38 | 16·2 | 33·6 | 11·0 | L | Cryst./fib. |
| +21 | +23 | 16·2 | 34·5 | 8·0 | L | Cryst. |
| | | | *Colville* B | | | |
| *As rolled*, t = 0·657 *in.* | | | | | | |
| +14 | +17 | 14·1 | 24·8 | 11·0 | L | Fib. |
| −10 | − 8 | 15·3 | 24·7 | 10·0 | L | Fib. |
| −20 | −15 | 14·7 | 26·2 | 9·5 | L | Cryst./fib. |
| −35 | −31 | 15·8 | 27·7 | 10·0 | L | Cryst./fib. |
| −43 | −39 | 16·1 | 27·6 | 7·5 | L | Cryst. |
| −45? | −41 | 17·1? | 26·9 | 8·0 | L | Cryst. |
| −14 | −10 | 16·1 | 26·9 | 12·0 | X | Fib. |
| −14 | −11 | 15·6 | 26·8 | 11·0 | X | Fib. |
| −20 | −17 | 15·0 | 27·2 | 9·5 | X | Cryst./fib. |
| −29 | −26 | 16·2 | 27·6 | 9·5 | X | Cryst./fib. |
| −38 | −32 | 17·7 | 27·5 | 8·5 | X | Cryst./patch fib. |
| −41 | −37 | 17·7 | 28·3 | 8·5 | X | Cryst. |

| Temp. at Yield, °C. | Temp. at Ultimate Stress, °C. | Yield Stress, tons/sq. in. | Ultimate Stress, tons/sq. in. | Elongation on 2 in., % | Direction of Rolling | Crystalline Area in Fracture, % |
|---|---|---|---|---|---|---|
| | | | *Colville* B | | | |
| *Water-quenched from 900° C.*, t = 0·645 *in.* | | | | | | |
| +20 | +20 | 18·9 | 29·8 | 8·0 | L | Fib. |
| −26 | −23 | 21·2 | 32·8 | 9·0 | L | Fib. |
| −34 | −31 | 21·4 | 33·0 | 8·5 | L | Fib. |
| −41 | −41 | 23·6 | 34·8 | 7·0 | L | Cryst./fib. |
| −57 | −56 | 23·1 | 34·6 | 7·0 | L | Fib./patch cryst. |
| | | | *Colville* D1 | | | |
| *Annealed at 900° C.*, t = 0·778 *in.* | | | | | | |
| +63 | +64 | 9·3 | 24·4 | 19·0 | L | Fib./patch cryst. |
| +55 | +52 | 9·6 | 24·6 | 19·0 | L | Cryst./fib. |
| +48 | +48 | 10·0 | 25·1 | 18·5 | L | Cryst./fib. |
| +38 | +39 | 10·1 | 26·1 | 13·5 | L | Cryst. |
| +16 | +20 | 10·6 | 27·3 | 14·0 | L | Cryst. |
| 0 | + 5 | 11·2 | 27·1 | 13·0 | L | Cryst. |
| *Normalized from 900° C.*, t = 0·775 *in.* | | | | | | |
| +37 | +37 | 14·2 | 28·9 | 16·0 | L | Fib. |
| +31 | +32 | 14·3 | 29·4 | 17·0 | L | Fib. |
| +20 | +23 | 14·7 | 29·8 | 15·0 | L | Cryst./fib. |
| − 4 | + 5 | 16·3 | 31·0 | 15·0 | L | Cryst./fib. |
| −14 | − 5 | 15·8 | 31·5 | 15·5 | L | Cryst./fib. |
| −20 | −12 | 17·0 | 32·0 | 12·5 | L | Cryst. |
| *Water-quenched from 900° C. and T. 650° C.*, t = 0·755 *in.* | | | | | | |
| +38 | +38 | 17·0 | 34·0 | 15·5 | L | Fib. |
| +32 | +34 | 19·2 | 35·2 | 14·5 | L | Fib. |
| +20 | +22 | 17·6 | 34·6 | 13·0 | L | Cryst./fib. |
| − 3 | + 2 | 19·3 | 36·5 | 16·0 | L | Cryst./fib. |
| −16 | − 9 | 20·6 | 37·0 | 14·0 | L | Cryst./fib. |
| −23 | −15 | 20·3 | 37·4 | ... | L | Cryst. |
| | | | *Colville* D2 | | | |
| *Annealed at 900° C.*, t = 1·017 *in.* | | | | | | |
| +74 | +77 | 9·5 | 25·0 | 18·5 | L | Fib. |
| +74 | +74 | 10·0 | 25·3 | 19·5 | L | Cryst./fib. |
| +61 | +61 | 10·1 | 25·9 | 16·5 | L | Cryst./fib. |
| +56 | +56 | 9·9 | 26·3 | 12·0 | L | Cryst. |
| +46 | +44 | 10·0 | 26·4 | 15·5 | L | Cryst. |
| +19 | +20 | 11·1 | 27·0 | 10·5 | L | Cryst. |
| *Normalized from 900° C.*, t = 1·020 *in.* | | | | | | |
| +70 | +71 | 13.6 | 28.7 | 18·0 | L | Fib. |
| +48 | +48 | 13·2 | 30·0 | 17·0 | L | Cryst./fib. |
| +20 | +24 | 14·5 | 31·0 | 15·5 | L | Cryst./fib. |
| 0 | + 9 | 15·5 | 31·9 | 12·0 | L | Cryst. |
| −12 | − 5 | 15·4 | 32·3 | 8·5 | L | Cryst. |
| −19 | −11 | 15·5 | 32·3 | 8·5 | L | Cryst. |
| *Water-quenched from 900° C. and T. 650° C.*, t = 1·009 *in.* | | | | | | |
| +58 | +59 | 15·8 | 32·3 | 19·5 | L | Fib. |
| +52 | +53 | 15·5 | 33·5 | 20·0 | L | Fib. |
| +44 | +48 | 16·2 | 33·2 | 18·5 | L | Cryst./fib. |
| +21 | +24 | 17·3 | 34·6 | 18·5 | L | Cryst./fib. |
| + 7 | +12 | 18·0 | 35·1 | 12·5 | L | Cryst. |
| − 6 | + 4 | 17·8 | 35·9 | 14·0 | L | Cryst. |
| | | | *Colville* E1 | | | |
| *As rolled*, t = 0·502 *in.* | | | | | | |
| +18 | +20 | 15·6 | 33·7 | 13·0 | L | Fib./patch cryst. |
| − 8 | − 1 | 16·9 | 35·0 | 12·0 | L | Cryst./fib. |
| −31 | −21 | 18·0 | 35·8 | ... | L | Cryst./fib. |
| −42 | −32 | 18·4 | 37·0 | 11·5 | L | Cryst./fib. |
| −48 | ? | 18·0 | 37·0 | 11·0 | L | Cryst. |
| −52 | −43 | 18·5 | 37·6 | 11·5 | L | Cryst. |
| | | | *Colville* E2 | | | |
| *As rolled*, t = 0·743 *in.* | | | | | | |
| +18 | +20 | 14·6 | 31·0 | 13·5 | L | 0 |
| − 8 | − 2 | 16·1 | 32·6 | 13·0 | L | 0 |
| −17 | −11 | 16·1 | 32·9 | 11·5 | L | 48 |
| −22 | −15 | 15·9 | 33·0 | 12·5 | L | 28·5 |
| −26 | −21 | 17·0 | 33·4 | ... | L | 86 |
| −35 | −30 | 17·6 | 35·6 | 9·0 | L | 77·5 |
| | | | *Colville* E3 | | | |
| *As rolled*, t = 1·000 *in.* | | | | | | |
| +85 | +84 | 13·9 | 31·6 | 18·0 | L | Fib. 2 or 3 grains crystalline |
| +61 | +61 | 14·2 | 32·7 | 17·0 | L | Cryst./fib. |
| +38 | +39 | 15·0 | 33·6 | 17·0 | L | Cryst./fib. |
| +18 | +22 | 14·8 | 34·1 | 16·0 | L | Cryst./fib. |
| − 6 | + 3 | 14·6 | 35·3 | 17·0 | L | Cryst./fib. |
| −29 | −18 | 15·1 | 36·5 | 12·5 | L | Cryst. |
| | | | *Plate* Z | | | |
| *As received*, t = 0·375 *in.* | | | | | | |
| +40 | +40 | 15·7 | 30·0 | 12·0 | L | Fib. |
| +31 | +31 | 15·9 | 31·7 | 13·0 | L | Fib. |
| +28 | +28 | 17·2 | 31·6 | 11·5 | L | Fib. |
| +26 | +27 | 15·5 | 28·5 | 7·0 | L | Cryst. |
| +24 | +25 | 16·8 | 30·4 | 8·0 | L | Cryst. |
| +17 | +18 | 16·3 | 30·9 | 8·3 | L | Cryst. |

* All specimens 1 in. wide, double-notched ¼ in., 45°, *t* = thickness of plate.

TABLE VIII—*Transition Ranges Estimated from Fractures*

| Plate No. | Nominal Thickness, in. | Treatment | Transition Range, ° C., from Appearance of Fracture | | | | Grain-Size, grains/sq. mm. | | Hardness, V.P.N. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Notched Tensile | Notched Bend | Notched Impact (Charpy) | | Ferrite | Ferrite + Pearlite | Surface | Middle |
| *A1* | ½ | As rolled | 2 to −18<br>0 to −26 | 15 to −8<br>−3 to −26 | 12 to −20<br>5 to −20 | L<br>X | 1460 | 2000 | 155, 143 | 134, 138 |
| | | Normalized 900° C. | −2 to −19<br>... | 17 to −12<br>10 to −25 | 33 to −17<br>33 to −17 | L<br>X | 1200 | 1650 | 154, 145 | 142, 150, 145 |
| *A2* | ½ | As rolled | 56 to 24<br>56 to 24 | 53 to 27<br>53 to 27 | 90 to 0<br>90 to 30 | L<br>X | 1175 | 1700 | 142, 142 | 136, 133, 133 |
| | | Normalized 900° C. | 40 to 8<br>... | 40 to 15<br>57 to 15 | 60 to −5<br>60 to −5 | L<br>X | 1400 | 1750 | 134, 124 | 147, 142, 143 |
| | | Normalized 850° C. | ... | 46 to 10 | 39 to 0 | L and X | ... | ... | ... | ... |
| *A3* | 1 | As rolled | 80 to 40<br>66 to 46 | 90 to 43<br>90 to 43 | ? to 25<br>? to 25 | L<br>X | 570 | 850 | 139, 142 | 151, 152, 152 |
| | | Normalized 900° C. | 80 to 30<br>... | 83 to 28<br>83 to 28 | 84 to 20<br>84 to 20 | L<br>X | 900 | 1300 | 123, 119 | 142, 138, 140 |
| | | Normalized 850° C. | ... | 78 to 25 | 74 to 20 | L and X | ... | ... | ... | ... |
| *B* | ½ | As rolled | −12 to −35<br>−14 to −33 | 0 to −10<br>32 to 3 | 55 to −8<br>55 to −8 | L<br>X | 729 | 837 | 116, 104 | 121, 117, 117 |
| | | Water-quenched 900° C. | −36 to ?<br>... | 10 to −25<br>10 to −25 | −4 to −34<br>15 to −33 | L<br>X | 2540 | ... | 154, 149 | 142, 132, 132 |
| *D1* | ½ | Annealed 900° C. | 65 to 44<br>... | ? to 25<br>? to 45 | ? to 70<br>? to 70 | L<br>X | 675 | 837 | 99 | 105, 101, 100 |
| | | Normalized 900° C. | 28 to −8<br>... | 32 to 5<br>32 to 5 | 50 to 0<br>50 to 0 | L<br>X | 837 | 1600 | 99, 107 | 114, 110, 107 |
| | | Water-quenched 900° C., tempered 650° C. | 28 to −12<br>... | 20 to −10<br>32 to 15 | 14 to −17<br>16 to −2 | L<br>X | ... | ... | 164, 125 | 150, 157, 152 |
| *D2* | 1 | Annealed 900° C. | 80 to 58<br>... | ? to 80<br>? to 95 | ? to 70<br>? to 70 | L<br>X | 684 | 990 | 97, 96 | 109, 106, 109 |
| | | Normalized 900° C. | 60 to 17<br>... | 70 to 30<br>70 to 30 | 85 to 10<br>85 to 10 | L<br>X | 1161 | 1800 | 126, 106 | 130, 126, 128 |
| | | Water-quenched 900° C., tempered 650° C. | 50 to 18<br>... | 82 to 30<br>82 to 30 | 65 to 12<br>90 to 23 | L<br>X | ... | ... | 124, 153 | 140, 135, 135 |
| *E1* | ½ | As rolled | 20 to −35<br>... | 27 to −2<br>27 to −2 | 51 to −6<br>51 to −6 | L<br>X | 870 | 1210 | 144, 151 | 146, 145, 154 |
| *E2* | ½ | As rolled | −7 to −18<br>0 to −28 | 6 to −38<br>33 to −5 | 18 to −20<br>40 to −5 | L<br>X | 783 | 1230 | 149, 143 | 145, 133, 144 |
| | | Normalized 850° C. | ...<br>... | 31 to −6<br>31 to −6 | 43 to −2<br>43 to −2 | L<br>X | ... | ... | ... | ... |
| *E3* | 1 | As rolled | 84 to −10<br>... | 70 to 10<br>70 to 10 | 47 to −15<br>47 to 3 | L<br>X | 785 | 1130 | 135, 168 | 150, 155, 164 |
| | | Normalized 850° C. | ...<br>... | 46 to 5<br>46 to 5 | 57 to −3<br>57 to −3 | L<br>X | ... | ... | ... | ... |
| *Z* | 0·375 | As received | 27<br>... | 70 to 40<br>50 to 18 | 90 to 60<br>90 to 50 | L<br>X | 760 | 1030 | 141, 152 | 138, 146, 138 |

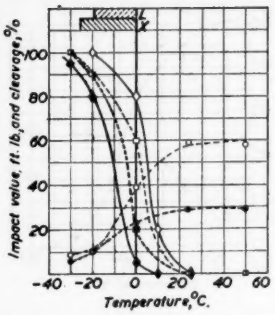



FIG. 7—Plate *A*1 (½ in.), as rolled

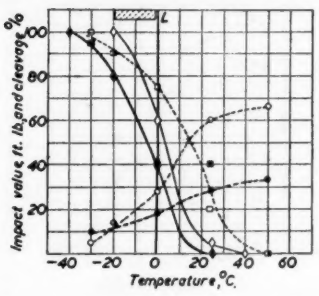



FIG. 8—Plate *A*1 (½ in.), normalized from 900° C.

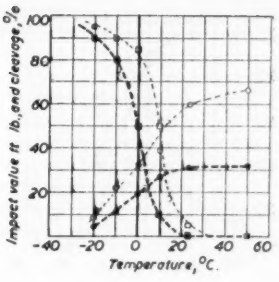



FIG. 9—Plate *A*1 (½ in.), normalized from 850° C.

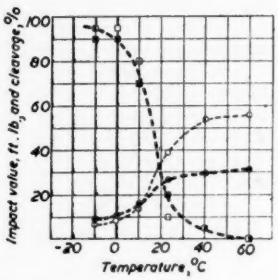



FIG. 10—Plate *A*1 (½ in.), normalized from 900° C. and annealed at 900° C.

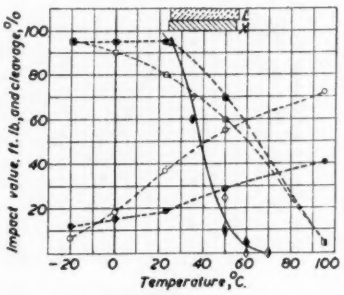



FIG. 11—Plate *A*2 (¾ in.), as rolled

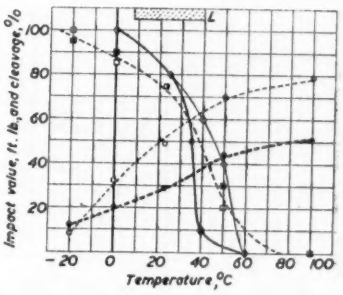



FIG. 12—Plate *A*2 (¾ in.), normalized from 900° C.

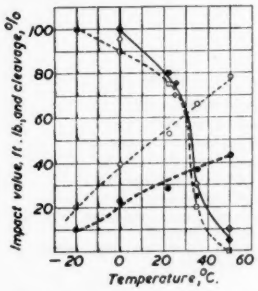



FIG. 13—Plate *A*2 (¾ in.), normalized from 850° C.

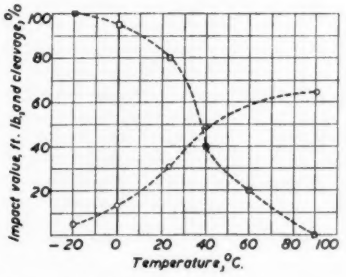



FIG. 14—Plate *A*2 (¾ in.), normalized from 850° C. and annealed at 850° C.

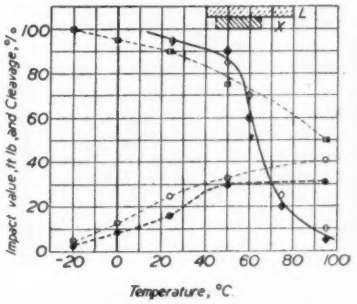



FIG. 15—Plate *A*3 (1 in.), as rolled

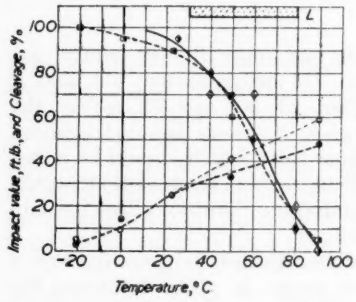



FIG. 16—Plate *A*3 (1 in.), normalized from 900° C.

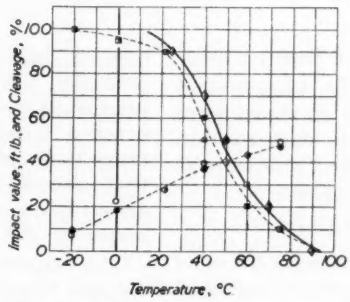



FIG. 17—Plate *A*3 (1 in.), normalized from 850° C.

KEY

-○- Length impact value
-●- Cross impact value
-□- Length impact cleavage, %
-■- Cross impact cleavage, %
-◊- Length bend cleavage, %
-♦- Cross bend cleavage, %
L Notched tensile transition range in length direction
X Notched tensile transition range in cross direction

FIGS. 7–17—Results of impact and notched bend tests for *A* plates

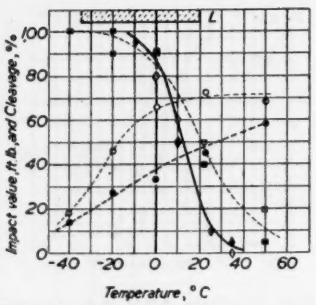



FIG. 18—Plate *E*1 ($\frac{1}{2}$ in.), as rolled

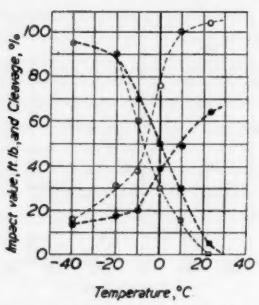



FIG. 19—Plate *E*1 ($\frac{1}{2}$ in.), normalized from 850° C.

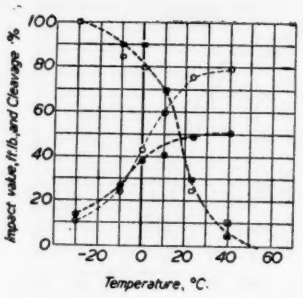



FIG. 20—Plate *E*1 ($\frac{1}{2}$ in.), normalized from 900° C. and annealed at 900° C.

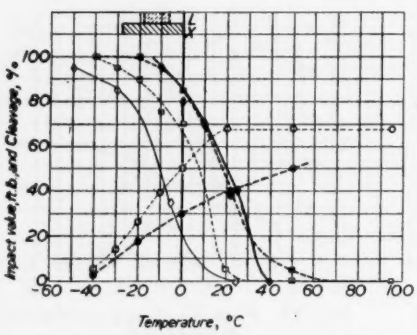



FIG. 21—Plate *E*2 ($\frac{3}{4}$ in.), as rolled

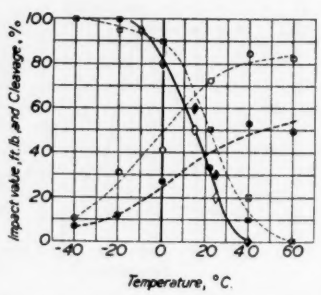



FIG. 22—Plate *E*2 ($\frac{3}{4}$ in.), normalized from 850° C.

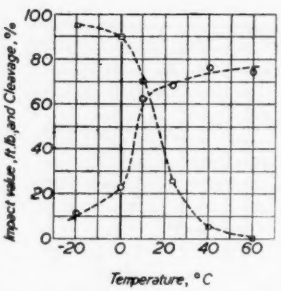



FIG. 23—Plate *E*2 ($\frac{3}{4}$ in.), normalized from 850° C. and annealed at 850° C.

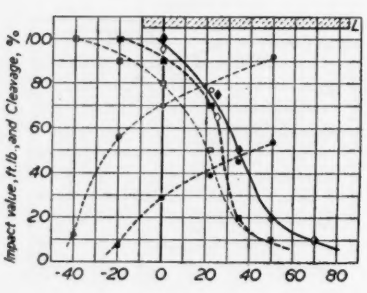



FIG. 24—Plate *E*3 (1 in.), as rolled

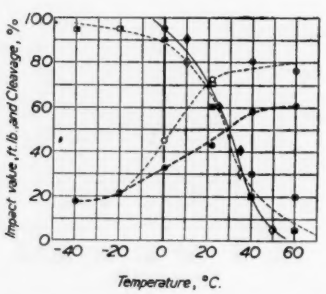



FIG. 25—Plate *E*3 (1 in.), normalized from 850° C.

KEY

- Length impact value
- Cross impact value
- Length impact cleavage, %
- Cross impact cleavage, %
- Length bend cleavage, %
- Cross bend cleavage, %
- L Notched tensile transition range in length direction
- X Notched tensile transition range in cross direction

FIGS. 18–25—Results of impact and notched bend tests for *E* plates

### *Impact and Notched Bend Tests*

The results obtained from the impact and notched bend tests are shown in graphical form in Figs. 7 to 36. Where determined, the transition ranges as obtained by the notched tensile tests have also been inserted in the graphs.

### Comparison of Test Results

On the whole there is good agreement between the transition range as determined by the notched bend, notched tensile, and impact tests when the cleavage areas in the fractures are taken as the criterion. There are, however, exceptions in the case of the softer and more ductile plates, *D*1 (annealed 900° C.), *D*2 (annealed 900° C.), and *B* (as rolled) (*see* Figs. 26, 30, and 33), where the notched tensile gives a much lower transition range than the other tests, but it should be noted that in these particular plates the tensile strengths are all below the minimum limit specified for ship plates by B.S.S.13.

The impact values do not in general show a marked transition range, in many instances the fall in impact values with temperature being gradual. The energy absorbed in impact is not a satisfactory guide to the temperature at which

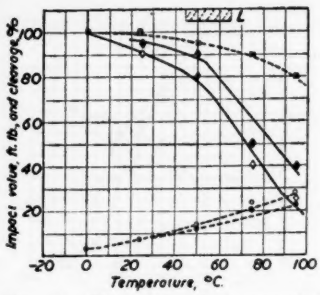



FIG. 26—Plate *D*1 (¾ in.), annealed at 900° C.

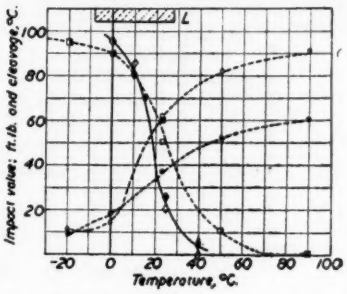



FIG. 27—Plate *D*1 (¾ in.), normalized from 900° C.

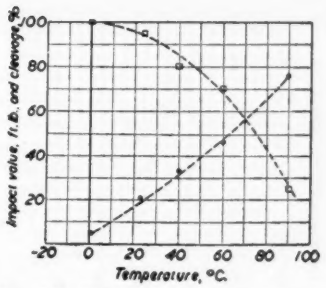



FIG. 28—Plate *D*1 (¾ in.), normalized from 850° C. and annealed at 850° C.

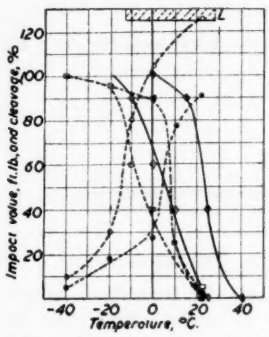



FIG. 29—Plate *D*1 (¾ in.), water-quenched from 900° C. and tempered for 2 hr. at 650° C.

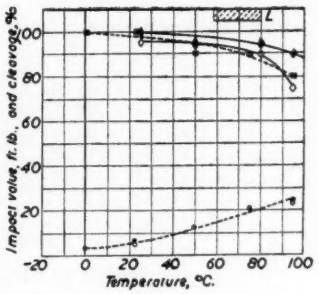



FIG. 30—Plate *D*2 (1 in.), annealed at 900° C.

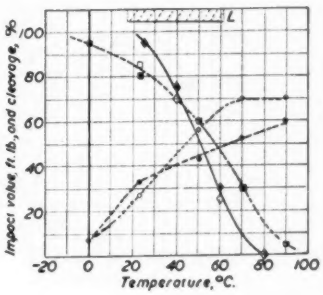



FIG. 31—Plate *D*2 (1 in.), normalized from 900° C.

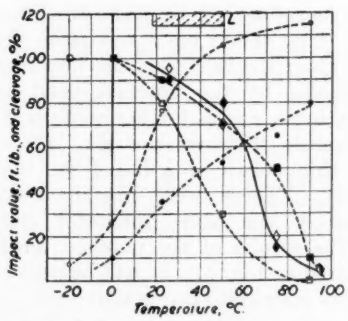



FIG. 32—Plate *D*2 (1 in.) water-quenched from 900° C., and tempered for 2 hr. at 650° C.

KEY
- Length impact value
- Cross impact value
- Length impact cleavage, %
- Cross impact cleavage, %
- Length bend cleavage, %
- Cross bend cleavage, %
- L Notched tensile transition range in length direction
- X Notched tensile transition range in cross direction

FIGS. 26–32—Results of impact and notched bend tests for *D*1 and *D*2 plates

cleavage fractures predominate. For example, the length test of plate *A*1, as rolled, gave an impact value of 24 ft. lb. at − 8° C., at which temperature the notched bend gives a 90% cleavage fracture, while the length test of plate *E*1, as rolled, gives the same degree of cleavage in the notched bend at 3° C., at which temperature the impact value is 67 ft. lb.

On the whole, the transition ranges in the notched bend tests are slightly higher than in the notched-tensile tests. This is considered to be due to the steeper strain gradient in the former. Superimposed on the strain gradient is the stress concentration caused by the notch. A "smoothing out" of the stress concentration is more readily effected in the notched tensile than in the notched bend test; hence the lower transition range, particularly of the softer plates, in the notched tensile tests.

It will be noted that in general the transition range as determined by the percentage cleavage in the impact test tends to be somewhat higher than that of the notched bend tests, although from considerations of size the reverse would be expected. This may be explained by the rate of loading, which is rapid in the impact test, and

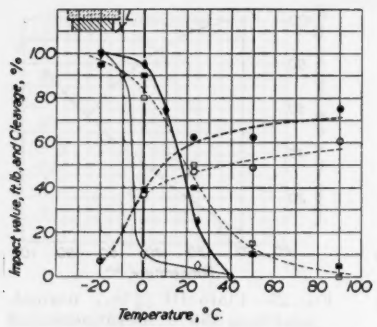



FIG. 33—Plate $B$ ($\frac{5}{8}$ in.), as rolled

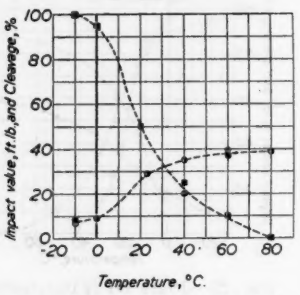



FIG. 34—Plate $B$ ($\frac{5}{8}$ in.), normalized from 900° C. and annealed at 900° C.

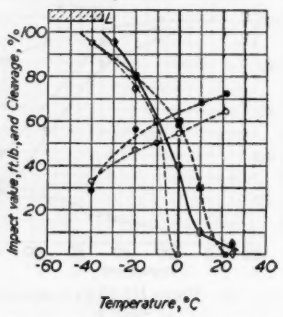



FIG. 35—Plate $B$ ($\frac{5}{8}$ in.), water-quenched from 900° C.

FIGS. 33–35—Results of impact and notched bend tests for plate $B$

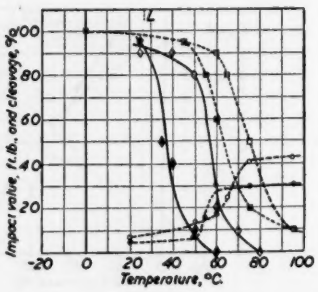



FIG. 36—Results of impact and notched bend tests for plate $Z$ (10 mm. thick)

KEY

-○- Length impact value
-●- Cross impact value
-□- Length impact cleavage, %
-■- Cross impact cleavage, %
-◊- Length bend cleavage, %
-◆- Cross bend cleavage, %
L Notched tensile transition range in length direction
X Notched tensile transition range in cross direction

a comparison between Hounsfield impact and Hounsfield notched bend results confirms this theory. These tests were carried out on the same size of test-piece, and the notched bend was found to give a much lower transition range (*see* Fig. 4).

More tests were done by the notched bend method than by the notched tensile method; further consideration of the results is based chiefly on the former. However, the discussion applies equally to the notched tensile tests and the impact fracture characteristics where these were determined.

In considering and comparing the temperature/notched-bend-fracture curves of the various steels, the shape of the curves as well as their position on the temperature scale should be borne in mind, although for convenience in discussing the results the temperature range only is considered here.

With one or two exceptions there is little difference between the transition range of the length and cross tests. In the following discussion, therefore, transition range, unless otherwise stated, means that range of temperature below which notched-bend-fractures, length or cross, have at least 90% cleavage, and above which notched bend fractures, length or cross, are at least 90% fibrous. For convenience, the transition ranges of the $A$, $E$, and $D$ plates in various conditions of heat-treatment are shown in Table IX.

## Effect of Plate Thickness

In the as-rolled condition, the transition range is raised as the thickness increases. Since the $A$ and $E$ series of plates were each made from a single cast of steel and check analyses show the plates from each set to be closely similar in composition, this effect must be due either to size effect as influenced by plate thickness or to structure. That this is not a test-piece size effect is evident from the fact that the phenomenon is shown equally by the notched bend and the impact fractures, and is further confirmed by the notched tensile tests on the $A1$, $A2$, and $A3$ plates of thicknesses of $\frac{1}{2}$ in., $\frac{3}{4}$ in., and 1 in. respectively. These were machined down to approximately the same thickness and again tested. The results of the notched tensile tests are compared in Fig. 37. It will be seen that the three plates maintain their relative positions, the most noticeable difference being in the decrease in the extent of the range. There is a considerable reduction in the temperature at which partial cleavage fractures were obtained in $A3$, but only a slight change in $A1$.

## Effect of Inclusions

Typical structures of the plates are illustrated in Figs. 38–58. In the $A$ and $E$ plates, the inclusions consist predominantly of silicates and sulphides, only $A2$ showing traces of alumina. In the $\frac{1}{2}$-in. plates the inclusions are more numerous and, particularly in plate $A1$, they form fairly long stringers segregated in the centre. These are less pronounced in the cross direction. In the $D$ plates, on the other hand, the

TABLE IX—*Transition Ranges for the* A, E, *and* D *Plates as Determined from Notched Bend or Impact Fractures*

| Specimen | Transition Range As rolled, °C. | Transition Range, Normalized, °C. | | Transition Range, Normalized and Annealed, °C. |
|---|---|---|---|---|
| | | 900° C. | 850° C. | |
| *A*1 | +15° to −26° (7)* | +17° to −25° (8) | +18° to −20° (9) | +30° to 0° (10) |
| *A*2 | +53° to +27° (11) | +57° to +15° (12) | +47° to +10° (13) | +71° to +8° (14) |
| *A*3 | +90° to +43° (15) | +83° to +28° (16) | +74° to +20° (17) | ... |
| *E*1 | +27° to −2° (18) | ... | +20° to −20° (19) | +36° to −10° (20) |
| *E*2 | +33° to −38° (21) | ... | +31° to −6° (22) | +33° to +1° (23) |
| *E*3 | +70° to +10° (24) | ... | +46° to +5° (25) | ... |
| | *Annealed 900° C.* | | | |
| *D*1 | 100° to +25° (26) | +32° to +5° (27) | ... | +98° to +29° (28) |
| *D*2 | 100° to +80° (30) | +70° to +30° (31) | ... | ... |

* Numbers in brackets indicate corresponding Figure numbers

inclusions consist predominantly of alumina in streaks segregated largely in the centre of the thickness. In addition, the 1-in. plate shows small elongated sulphide and silicate inclusions. In neither case is there any appreciable difference between the length and cross directions.

Impact values are different in the length and cross directions, particularly at high temperatures, but there is little apparent difference in the amount of cleavage in the corresponding fractures.

It is possible that the stringer inclusions in the ½-in. plates may have contributed to the lowering of the transition range and further investigations will be made on this question.

### EFFECT OF NORMALIZING AND OF RATE OF COOLING

In the as-rolled condition, etched microstructures show progressive coarsening as the plate thickness increases. This is probably due, in part at least, to the higher finishing temperature of the rolling of the thicker plates. It should be noted, however, that these effects are more marked in the *A* than in the *E* series. Plates *A*2 and *A*3 were normalized at 900° C. and 850° C. Both the structures and the transition ranges show that the latter is the better normalizing temperature. Plates *E*2 and *E*3 were also normalized at 850° C. The transition range of these ¾-in. and 1-in. plates has been lowered by normalizing, but although the structure in this condition, particularly of the ¾-in. plates, is closely similar to that of the corresponding ½-in. plates as rolled, the transition range is still higher than that of the ½-in. plates. It should be remembered, however, that the structure as revealed by the microscope does not give a complete picture of the condition of the steel. Different rates of cooling from the normalizing temperature affect the amount of carbide precipitated from the ferrite, though this is usually too small in amount to be visible under the microscope. Nevertheless, the mechanical properties may be profoundly modified. For example, no difference in microstructure is observed between mild steel when water-quenched and when air-cooled from 690° C., although the former reveals marked quench-age-hardening.

It will also be noted that the thicker *E* plates, whether as rolled or normalized, give a lower transition range than the corresponding *A* plates. On the other hand, the ½-in. *E* plate, as rolled, has a higher transition range than the ½-in. *A* plate, as rolled. This may be due, in part, to a difference in finishing temperature. Accordingly, these plates were normalized at 850° C. and the results obtained (Figs. 9 and 19, and Table IX) show that while *A*1 has been made slightly worse



XUM

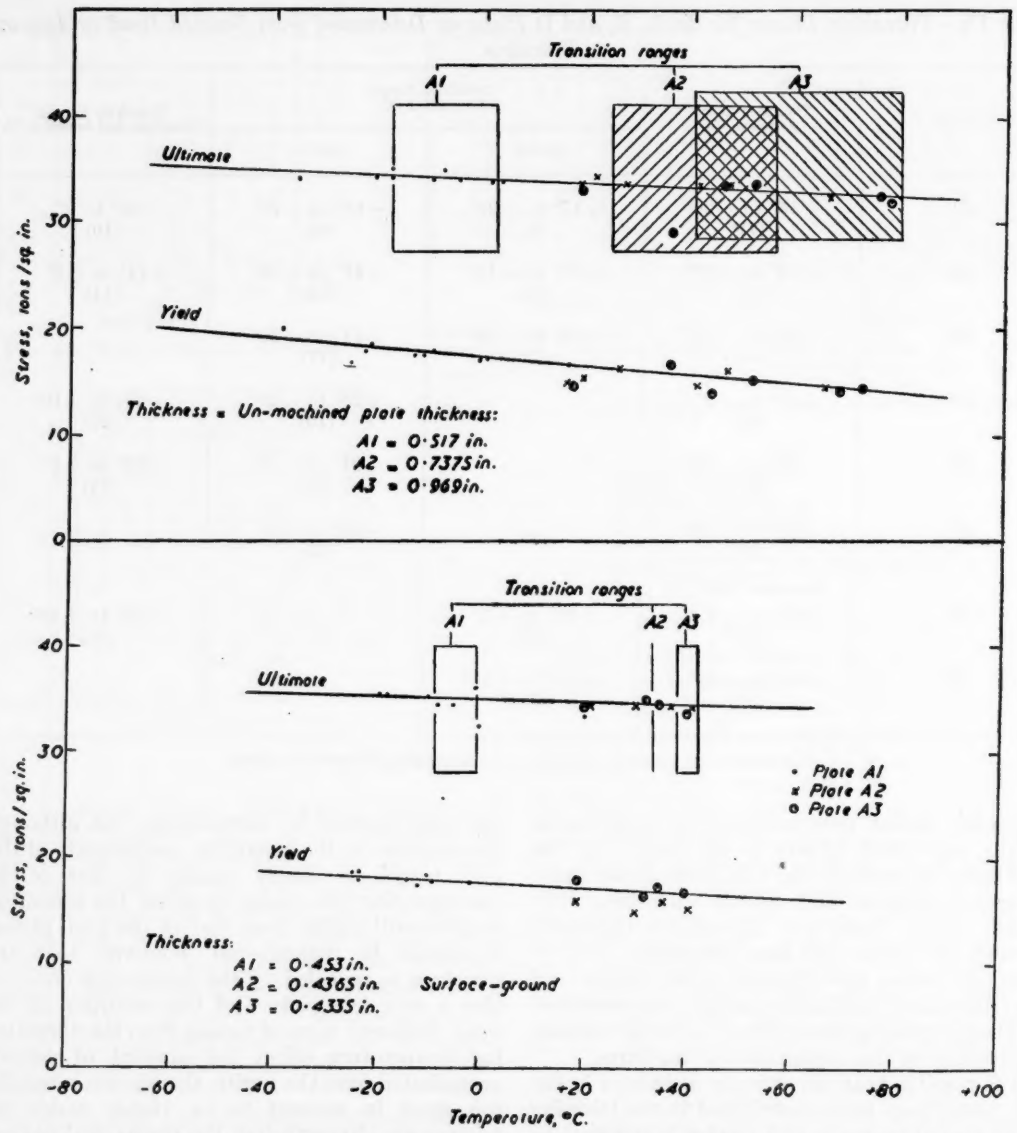



FIG. 37—Effect of plate thickness on the transition temperatures of *A* plates (in the length direction ; specimens 1 in. wide with 2 **V** notches, $\frac{1}{8}$ in. and 45°)

by this treatment, *E*1 has been slightly improved, so that in the normalized condition there is practically no difference between the two plates. These plates were also annealed at 900° C. (Figs. 10 and 20, and Table IX), and it will be noted that while there is little difference between their transition ranges, the *E* plates give much better impact values. Even in the annealed condition, the $\frac{1}{2}$-in. plates are better than the corresponding $\frac{3}{4}$-in. plates in the normalized condition.

The effects of normalizing and of slow rates of cooling are most marked in the *D* plates. The transition range is greatly lowered by normalizing, and subsequent slow cooling raises the transition range to an almost equal extent. Further reference to this is made below.

### EFFECT OF FERRITIC GRAIN-SIZE

Examination of the microstructures (Figs. 44–57) and of the grain-size counts shown in Table VII, indicates that, in general, a smaller ferritic grain-size gives a lower transition range. This effect may, however, not be entirely due to grain-size *per se*, but to changes in the internal structure brought about by the treatment which

FIG. 38—Plate *A*1 ($\frac{1}{2}$ in.)

FIG. 39—Plate *A*2 ($\frac{3}{4}$ in.)

FIG. 4 —Plate *E*1 ($\frac{1}{2}$ in.)

FIG. 41—Plate *E*2 ($\frac{3}{4}$ in.)

FIG. 42—Plate *D*1 ($\frac{3}{4}$ in.)

FIG. 43—Plate *D*2 (1 in.)

FIGS. 38–43.—Unetched length sections of plates *A*1, *A*2, *E*1, *E*2, *D*1, and *D*2. × 120
(Reduced to two-thirds linear in reproduction)

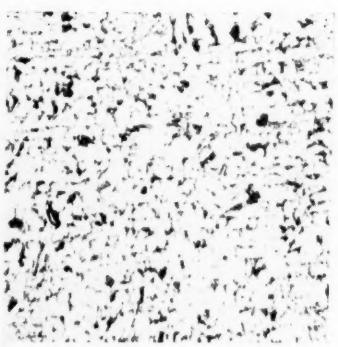


FIG. 44—Plate *A*1 ($\frac{1}{2}$ in.)

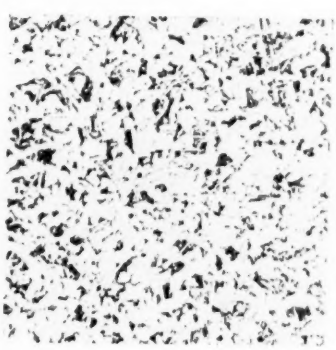


FIG. 45—Plate *A*2 ($\frac{3}{4}$ in.)

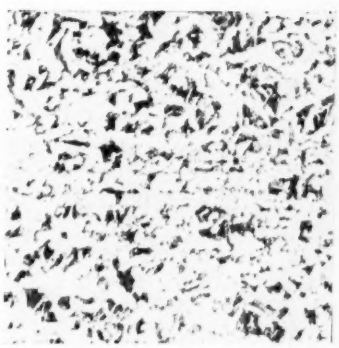


FIG. 46—Plate *A*3 (1 in.)

FIGS. 44–46.—As rolled microstructures of plates *A*1, *A*2, and *A*3. Etched with nital. × 50



XUM

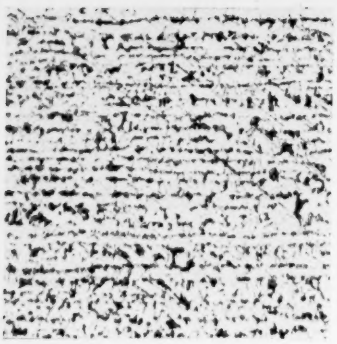


FIG. 47—Plate *A*2 (¾ in.), normalized from 850° C.

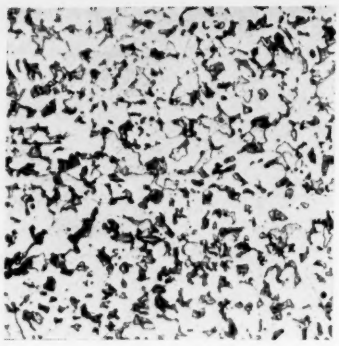


FIG. 48—Plate *A*3 (1 in.), normalized from 850° C.

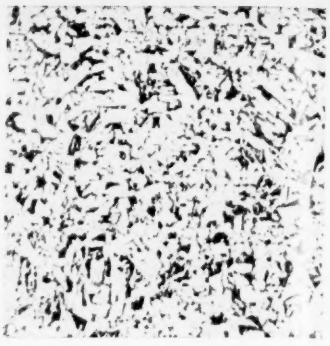


FIG. 49—Plate *E*1 (½ in.), as rolled

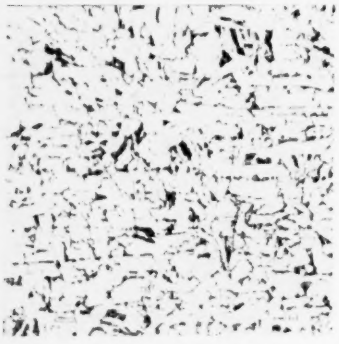


FIG. 50—Plate *E*2 (¾ in.), as rolled

FIG. 51—Plate *E*3 (1 in.), as rolled

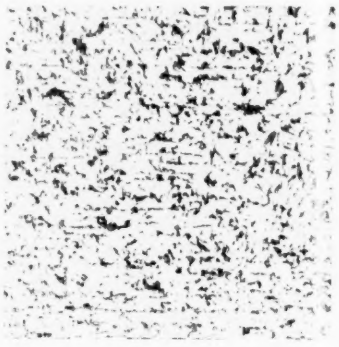


FIG. 52—Plate *E*2 (¾ in.), normalized from 850° C.



FIG. 53—Plate *E*3 (1 in.), normalized from 850° C.



FIG. 54—Plate *D*1 (¾ in.), annealed at 900° C.



FIG. 55—Plate *D*1 (¾ in.), normalized from 900° C.

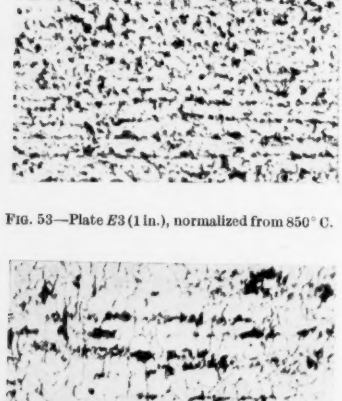


FIG. 56—Plate *D*2 (1 in.), annealed at 900° C.

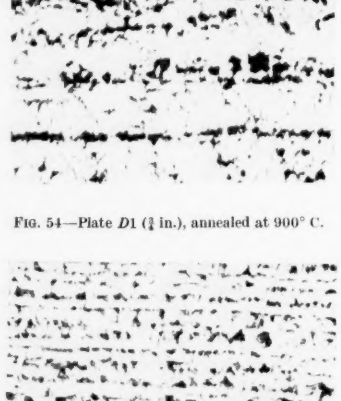


FIG. 57—Plate *D*2 (1 in.), normalized from 900° C.

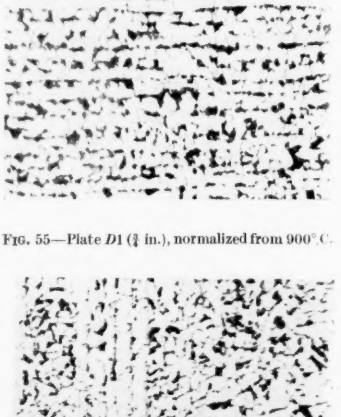


FIG. 58—Plate *Z* (10 mm.), as received

FIGS. 47–58—Microstructures of *A*, *E*, *D*, and *Z* plates. Etched with nital. × 50

*Barr and Tipper*]
*To face p. 237*]

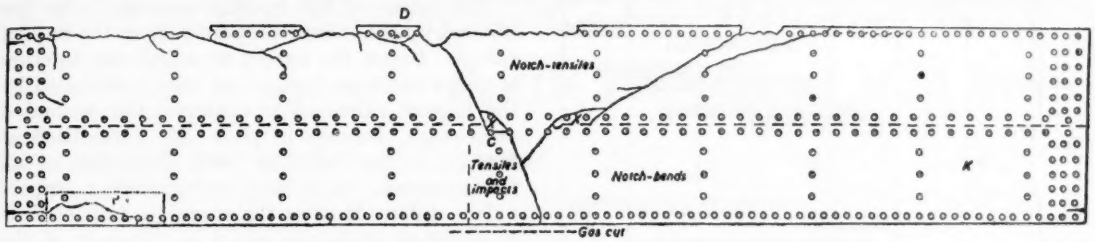



FIG. 59—Cutting diagram for plate *Z* (Scale : 1 in. = 3 ft. 6 in.)

results in a finer grain-size. The effect of inherent (McQuaid-Ehn) grain-size was not examined. It will be noted that all the steels are of the coarse-grained type.

### EFFECT OF COMPOSITION

Consideration of the results of the *A*, *E*, and *D* plates indicates that there may be some relation between the manganese content of mild steel and the transition range, and, what is more important, it would appear that the lower the manganese content the more susceptible is the steel to slow rates of cooling from the rolling or normalizing temperature. In the case of the *A* and *D* ½-in. plates, this applies to the impact values only, but in the *A*, *E*, and *D* ¾-in. plates, which comprise the only complete annealed series, it applies to both the impact value and the degree of cleavage.

It will be noted that, apart from carbon and manganese contents, plates *A*, *E*, and *D* show differences in composition in respect of silicon and residual elements (nickel, chromium, molybdenum, copper, and tin). Such differences are unavoidable in production and it is possible that they may have had an appreciable influence on the results obtained.

Barr* has shown that low-manganese plates ¾ in. and 1 in. thick in the as-rolled condition tend to give low Izod impact values at room temperature. He also compared the Izod impact values of various plates in the normalized and in the annealed conditions. It was shown that the reduction in impact value of annealed as against normalized plates was greater in plates of low manganese content. (In all these plates the residual elements were low and reasonably uniform.) Striking confirmation of this is shown by the tests on plates *A*2, *E*2, and *D*1, described above. These plates were all ¾ in. thick and were normalized from 850° C., and then annealed at 850° C., all the test-pieces being treated simultaneously in the same furnace. Impact tests in the length direction were then carried out with the results shown in Figs. 14, 23, and 28, and Table X.

In considering the significance of these results it should be borne in mind that the rate of cooling of plates after rolling may vary from that corresponding to normalizing to that corresponding to annealing, depending upon rolling conditions and handling on the mill floor. It will be noted that the transition range of the *D*1 plates annealed at 850° C. (Fig. 28) is lower than that of the same plates annealed at 900° C. (Fig. 26). This may be due not only to different rates of cooling, but also to the different initial temperatures. This aspect of the subject will be further investigated.

The cleanness of plate *Z* was satisfactory and the structure (Fig. 58) was normal. The high transition range and the low impact values may therefore be attributed to the nitrogen content, which is abnormally high even for Bessemer steel.

A cross strip from section *C* (Fig. 59) was normalized at 900° C., and then gave the following properties :

| | |
|---|---|
| Yield point, tons/sq. in. ... ... | 17·8 |
| Maximum stress, tons/sq. in. ... | 29·3 |
| Elongation : | |
| On 8-in. gauge length, % ... | 18 |
| On 4√ area gauge length, % | 30 |
| Reduction of area, % ... ... | 51 |
| Izod impact value at 18° C., ft. lb. ... ... ... ... | 20, 13, 26 (80% cleavage) |

The failure of the normalizing treatment to bring about any marked improvement in impact value shows that the plate is of very inferior quality.

### EFFECT OF WATER-QUENCHING

Samples of plate *B* were water-quenched and samples of plates *D*1 and *D*2 were water-quenched and tempered. Water-quenching lowered the

TABLE X—*Impact Values for Plates* D*1*, A*2, and* F*2*

| | Transition Range, ° C. | Impact Values, ft. lb. | |
|---|---|---|---|
| | | 20° C. | 0° C. |
| *D*1 | + 98 to + 29 | 18 | 5 |
| *A*2 | + 71 to + 8 | 28 | 14 |
| *E*3 | + 33 to + 1 | 68 | 23 |

* Report of the Conference on "Brittle Fracture in Mild Steel Plates," Cambridge, 1945.



XUM

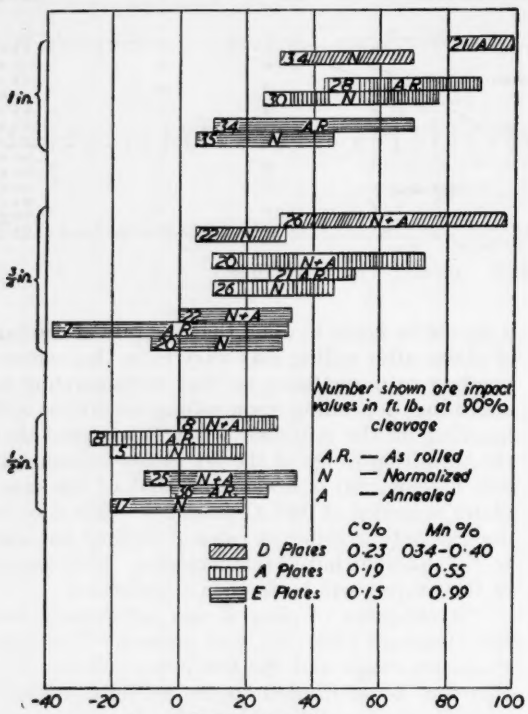



FIG. 60—Transition ranges as determined from notched bend and impact tests for *D*, *A*, and *E* plates

transition range of plate *B*. Compared with normalizing, water-quenching and tempering had little effect on plate *D*1 and slightly raised the transition range of *D*2. On the other hand, the impact values of all three plates at all temperatures were raised despite the increase in tensile strength.

### FURTHER CONSIDERATION OF IMPACT TESTS

In general, the impact value is higher when the test-piece is cut in the direction of rolling than when it is cut in the cross direction. Directional properties depend upon the relative amounts of length and cross rolling of the plates and the cleanness of the steel. Inclusions are elongated in the length direction and the more inclusions present the more marked will be the directional properties. The higher impact value in test-pieces cut in the length direction may be due to greater ductility, indicated by a higher percentage reduction in area obtained in tensile test-specimens cut in this direction. Other factors, however, may swamp the influence of ductility in an impact test, as, for example, appears to have occurred in plates *D*1 and *D*2 in the annealed condition. These plates are ductile in a tensile test, but give low impact values. Why some normally ductile plates give very low impact values must be the subject for still further investigation.

The nature of the fracture appears to be less affected by directional properties than the impact values. Hence the extent to which the fracture is of the cleavage type is not always revealed by the impact value. For example, the estimated percentage cleavage in plate *A*2, normalized at 900° C., is the same in both directions at all temperatures, while the corresponding impact values differ. Most of the energy in impact tests is absorbed while the metal at the root of the notch is deforming plastically before a crack is initiated. Thus, a high impact value may be accompanied by a fracture which is mainly cleavage. This is strikingly illustrated in plates *A*1, as rolled, and *D*2, water-quenched. At 25° C., the cross test of the former gave an impact value of 28 ft. lb., with 100% fibrous fracture, while the length test of the latter gave an impact value of 80 ft. lb., with 80% cleavage.

The results of the impact tests have shown that the effect of increasing plate thickness in raising the transition temperature range is minimized by increased manganese content. This may be attributed to the beneficial influence of manganese when the steel has been subjected to slow rates of cooling.

### CONCLUSIONS

(1) The effect of temperature on the behaviour of mild-steel plates was examined by means of notched-bar impact, notched bend, and notched tensile tests and the extent of cleavage present in the fractures of the test-pieces was measured.

(2) The temperature ranges of transition from tough to brittle fracture as determined by each of these different tests were generally in good agreement.

(3) This transition range is raised by an increase in the ferritic grain-size, by an increase in plate thickness, and by slow cooling after normalizing.

(4) In the very soft steels the notched tensile test gives a lower transition range than the notched bend or impact test.

(5) A high impact value may be accompanied by a fracture which is mainly cleavage. From the results of the fracture tests (notched bend or impact) on the *A*, *E*, and *D* plates, summarized in graphical form in Fig. 60, the following tentative conclusions may be drawn. These conclusions are subject to confirmation on tests being carried out on a series of steels containing low residuals and with varying carbon and manganese.

(6) The effect of increasing plate thickness in raising the transition range is less marked in the plates with high manganese content.

(7) The effect of slow rates of cooling in raising the transition range is reduced in the plates with high manganese content.

# Effect of the Manganese/Carbon Ratio on the Brittle Fracture of Mild Steel*

*By W. Barr, A.R.T.C., F.I.M.,† and A. J. K. Honeyman, B.Sc., F.I.M.†*

SYNOPSIS

*A series of four mild steels was made in which the only significant variable was the manganese/carbon ratio. The residual elements were low and the tensile strengths were approximately the same for each steel. The notched-bar impact properties of these steels in the annealed and in the normalized conditions have been determined. It was found that increasing the manganese/carbon ratio lowers the range of transition from tough to brittle fracture, increases the impact values at all temperatures, and tends to result in finer McQuaid-Ehn and ferritic grain-sizes. A practical recommendation is made that for structural steels for shipbuilding purposes, the manganese/carbon ratio should be not less than 3·0.*

## INTRODUCTION

In a report by Barr and Tipper on "Brittle Fracture in Mild-Steel Plates,"‡ it was shown that there was some relation between the manganese content of mild steel and the range of transition from tough to brittle fracture. At the same time, it was pointed out that the steels tested showed differences in composition in respect of silicon and residual elements (nickel, chromium, and molybdenum), and that such differences, unavoidable in production, may have had an appreciable influence on the results obtained. Another variable arising from differences in composition is the tensile strength, which increases with increasing carbon and/or manganese. Accordingly, a series of tests were undertaken on steels in which residuals were low and reasonably uniform from cast to cast, and the carbon and manganese contents were adjusted to give as nearly as possible the same tensile strength for each steel.

## EXPERIMENTAL PROCEDURE

### *Preparation of Specimens*

Four high-frequency 18-lb. casts were made using the same quality of scrap, containing the lowest residuals obtainable. In order to ensure that sound material would be obtained from the steel containing low manganese, the casts were made with a silicon content of 0·12–0·15%, but no other deoxidants were added. As can be seen from the analyses, the residuals are low and the only significant variation in analysis between the steels is in carbon and manganese contents (*see* Table I).

The ingots were forged to $1\frac{3}{4}$ in. square and the heads cropped. The $1\frac{3}{4}$ in. square billets were then rolled to $\frac{5}{8}$ in. square and check analyses were made from each end of the bars. These showed no significant variation from the analyses shown.

The Ac range of each steel was determined by the dilatometric method and the test-pieces were normalized and annealed from a temperature approximately 50° C. above the upper limit of the Ac range.

The bars were cut into 12-in. lengths for heat-treatment.

‡ *Journal of the Iron and Steel Institute*, 1947, vol. 157, Oct., pp. 223–238.

* Paper MG/32/47 of the Metallurgy (General) Division of the British Iron and Steel Research Association. Received 17th July, 1947. The views expressed are the authors' and are not necessarily endorsed by the Divisional Panel as a body.

† Messrs. Colvilles, Ltd., Glasgow.

TABLE I—*Chemical Analysis of Steels*

| Cast No. | C, % | Si, % | S, % | P, % | Mn, % | Ni, % | Cr, % | Mo, % | Cu, % | Sn, % |
|---|---|---|---|---|---|---|---|---|---|---|
| 1229 | 0·19 | 0·12 | 0·034 | 0·012 | 0·27 | 0·04 | 0·03 | 0·03 | 0·035 | 0·01 |
| 1230 | 0·17 | 0·13 | 0·033 | 0·013 | 0·68 | 0·03 | 0·03 | 0·03 | 0·040 | 0·01 |
| 1278 | 0·115 | 0·13 | 0·029 | 0·015 | 0·89 | 0·04 | 0·03 | 0·03 | 0·040 | 0·01 |
| 1232 | 0·10 | 0·15 | 0·027 | 0·016 | 1·19 | 0·05 | 0·04 | 0·02 | 0·040 | 0·01 |

TABLE II—*Grain-Size and Heat-Treatment of Steels*

| Cast No. | A.S.T.M. (McQuaid-Ehn) Grain-Size | Critical Range, ° C. | Normalizing Temperature, ° C. | Annealing Temperature, ° C. |
|---|---|---|---|---|
| 1229 | 1–6 | 725–845 | 900, 860, 930 | 860, 900 |
| 1230 | 2–5 | 725–845 | 900, 860, 930 | 860, 900 |
| 1278 | 3–5 | 740–845 | 900 | |
| 1232 | 3–5 | 725–855 | 900, 880, 950 | 880, 900, 950 |

The bars to be normalized were placed in a furnace at the required temperature, held there for 1 hr., and cooled separately in air.

The bars to be annealed were first normalized, then placed in the furnace at the required temperature, soaked for 1 hr., and cooled in the furnace. The heat capacity of the furnace was large compared with that of the specimens. The time required to cool from the initial temperature to 600° C. was approximately 4 hr.

### *Microscopic Examination*

Structures of all the steels in the normalized and in the annealed conditions are illustrated in Figs. 1–18. The A.S.T.M. (McQuaid-Ehn) grain-size was also determined. The results are shown in Table II which also includes the Ac ranges and the heat-treatment data.

### *Mechanical Tests*

Tensile tests were carried out in the normalized and annealed conditions and are recorded in Table III. It will be noted that in the normalized condition, the tensile strengths of all four steels are between 27·9 and 28·9 tons/sq. in.

Impact tests were carried out in the manner described in the report referred to above. The degree of cleavage was determined by projecting the fractured face on a screen at a magnification of 6 diameters, the relative areas of cleavage and fibrous fracture being measured by planimeter. The results are shown in Figs. 19–26 and summarized in Fig. 27.

## CONSIDERATION OF RESULTS

### *Grain-Size*

As has already been stated, the only significant variation in composition between the four steels is in the carbon and manganese contents. However, this variation might be expected to affect the grain-size and the grain-growth characteristics of the steels.

The McQuaid-Ehn grain-sizes (Table II) indicate that increasing the manganese contents tends to give a finer grain-size. This may be due to the deoxidizing effect of manganese. Comparison of the microstructures of the steels normalized approximately 50° C. above the Ac range shows that steel 1229 with high carbon and low manganese has the largest grain-size. This steel has the highest transition range, in both the normalized and annealed conditions. All the steels show evidence of grain growth as the normalizing temperature is increased, but this grain growth is appreciable only in steel 1229.

The effect on the transition range of increasing the ferritic grain-size by raising the normalizing temperature is shown for three of the steels in Fig. 27. The effects are slight in both the normalized and annealed conditions in comparison with effects due to difference in composition, and the relative order of merit of the steels is unaffected. The only exception is steel 1232 after annealing at 950° C. This excessively high temperature has not greatly affected the transition range in the normalized condition, but has appreciably raised the transition range in the annealed condition. Steels 1229, normalized 860° C., 1230, normalized 900° C., and 1232, normalized 880° C., have similar ferritic grain-sizes, yet show wide differences in the transition range in both the normalized and annealed conditions. While steel 1229 is particularly subject to grain growth, the increased grain-size does not greatly affect the transition range.

### *Effect of Manganese/Carbon Ratio*

It is clearly shown in Fig. 27 that as the manganese/carbon ratio increases, the transition range is lowered, both in the normalized and in the annealed conditions. This beneficial effect of increasing the manganese/carbon ratio is most pronounced, particularly in the normalized steels, in the manganese/carbon ratio range of 1·5–4. When the manganese/carbon ratio is particularly high, remarkably good low-temperature properties are obtained in the normalized condition. It will also be noted that when the transition range is very low, it is also very narrow.

### *Effect of Annealing*

Although annealing causes a decrease in tensile strength, the ductility is generally reduced and the transition range of all the steels is raised. At the same time the transition covers a wide range of temperature. In the annealed condition, the steels remain in the same order of merit, the



XUM

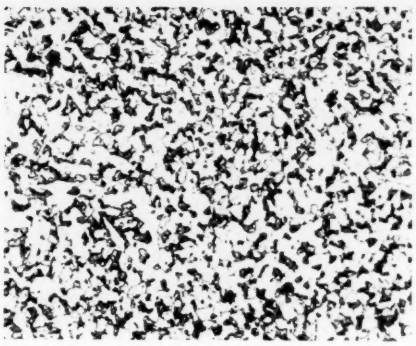


FIG. 1—Normalized from 860° C. × 100

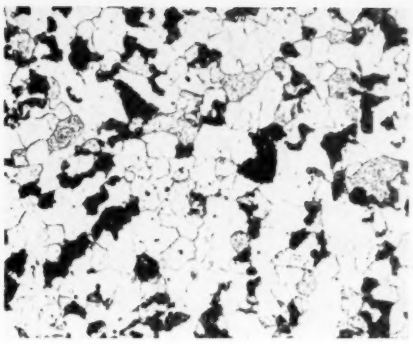


FIG. 2—Normalized and annealed 860° C. × 100

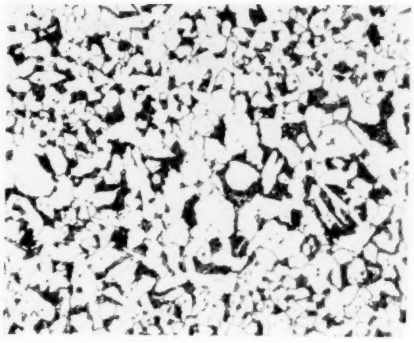


FIG. 3—Normalized from 900° C. × 100

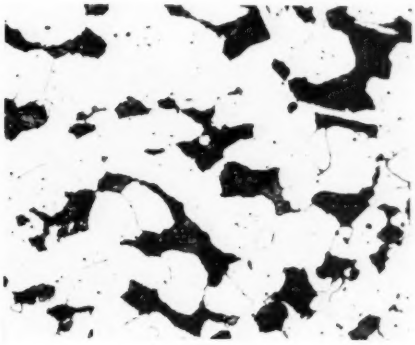


FIG. 4—Normalized and annealed 900° C. × 100

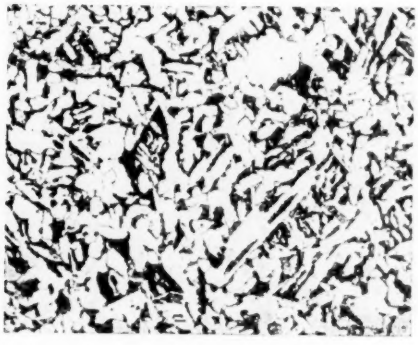


FIG. 5—Normalized from 930° C. × 100

FIGS. 1–5—Steel 1229 (0·19% carbon, 0·27% manganese), etched in 2% nital



XUM

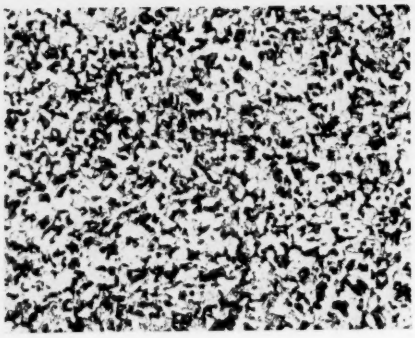


FIG. 6—Normalized from 860° C. × 100

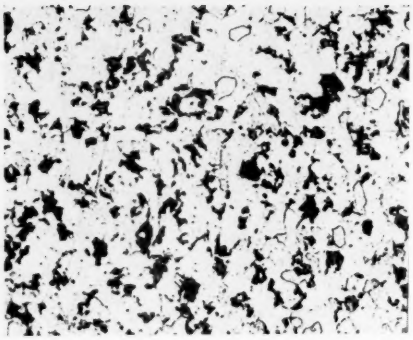


FIG. 7—Normalized and annealed 860° C. × 100

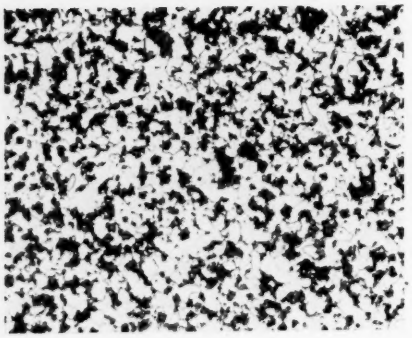


FIG. 8—Normalized from 900° C. × 100

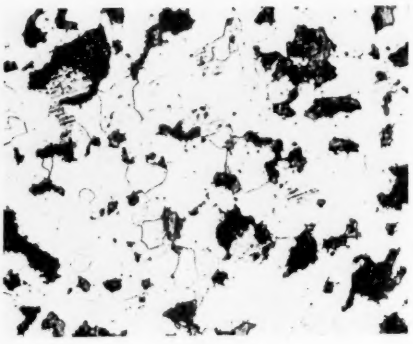


FIG. 9—Normalized and annealed 900° C. × 100

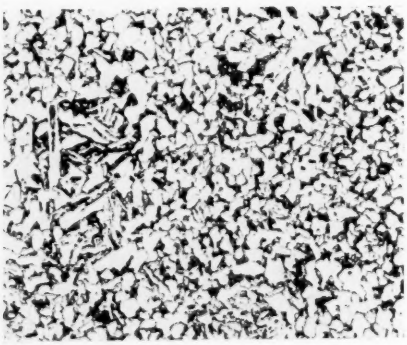


FIG. 10—Normalized from 930° C. × 100

FIGS. 6–10—Steel 1230 (0·17% carbon, 0·68% manganese), etched in 2% nital

XUM

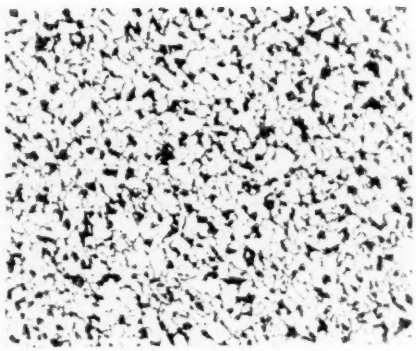


FIG. 11—Normalized from 900° C. × 100

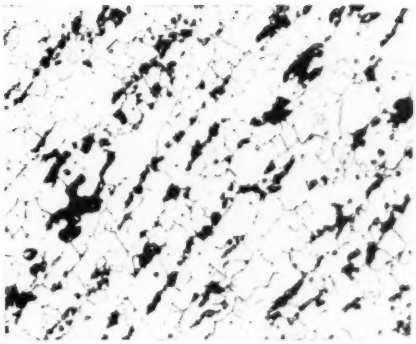


FIG. 12—Normalized and annealed 900° C. × 100

FIGS. 11 and 12—Steel 1278 (0·115% carbon, 0·89% manganese), etched in 2% nital

XUM

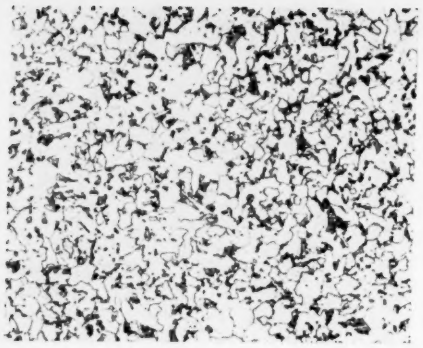


FIG. 13—Normalized from 880° C. × 100

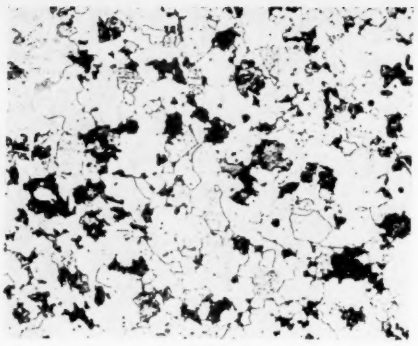


FIG. 14—Normalized and annealed 880° C × 100

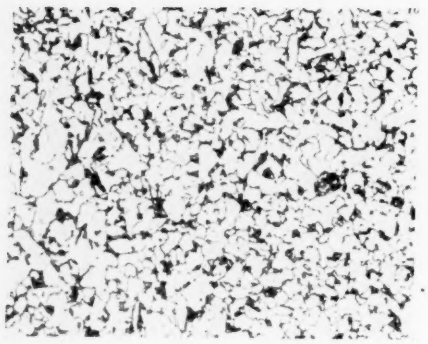


FIG. 15—Normalized from 900° C. × 100

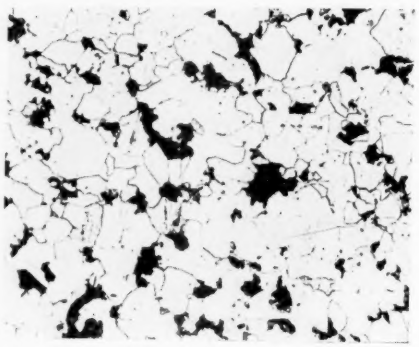


FIG. 16—Normalized and annealed 900° C. × 100

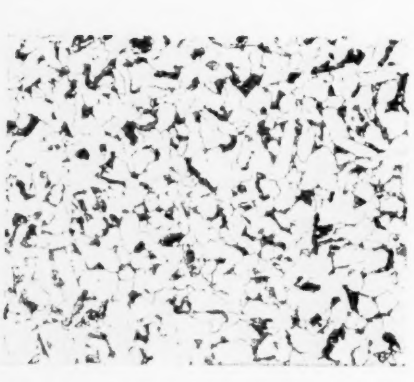


FIG. 17—Normalized from 950° C. × 100

FIG. 18—Normalized and annealed 950° C. × 100

FIGS. 13–18—Steel 1232 (0·10% carbon, 1·19% manganese), etched in 2% nital

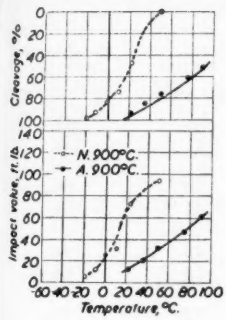



FIG. 19—(*Left*) Steel 1229 (0·19% carbon, 0·27% manganese)

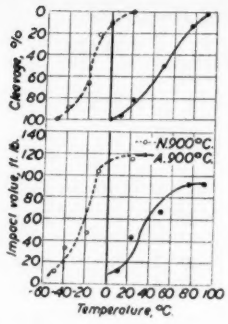



FIG. 20—(*Right*) Steel 1230 (0·17% carbon, 0·68% manganese)

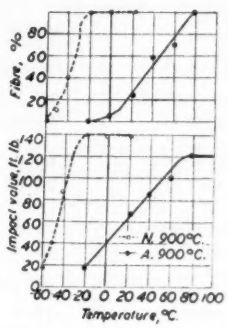



FIG. 21—(*Left*) Steel 1278 (0·115% carbon, 0·89% manganese)

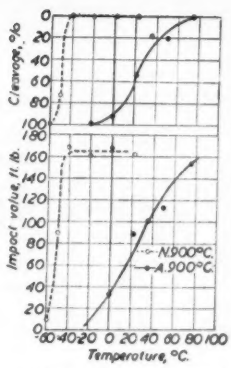



FIG. 22—(*Right*) Steel 1232 (0·10% carbon, 1·19% manganese)

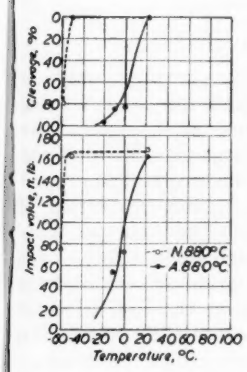



FIG. 23—(*Left*) Steel 1232 (0·10% carbon, 1·19% manganese)

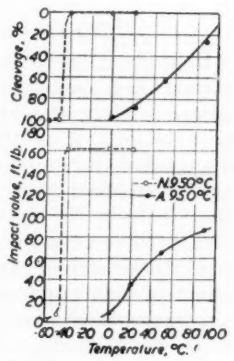



FIG. 24—(*Right*) Steel 1232 (0·10% carbon, 1·19% manganese)

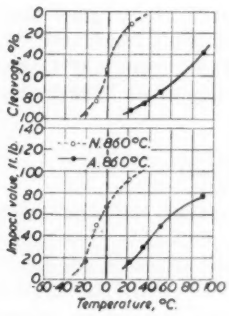



FIG. 25—(*Left*) Steel 1229 (0·19% carbon, 0·27% manganese)

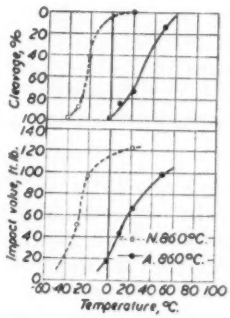



FIG. 26—(*Right*) Steel 1230 (0·17% carbon, 0·68% manganese)

FIGS. 19–26—Cleavage and impact values after various heat-treatments

higher the manganese/carbon ratio, the lower being the transition range.

It appears that the raising of the transition range by annealing is due to some change in the condition of the carbides and that raising the manganese/carbon ratio decreases the rate at which this change takes place. Increasing the carbon increases the quantity of carbide, while increasing the manganese alters its composition and behaviour. The more carbide present the more easily does the carbide change take place, and the more manganese present the more sluggish is the change. Thus, the differences in the transition range between the steels depends on the composition and the rate of cooling from the normalizing temperature. However, for any given rate of cooling between normalizing and full annealing, the steels will be placed in the same order of merit with regard to the transition range as they are in the normalized condition, and it is therefore in this condition that steels should be compared.

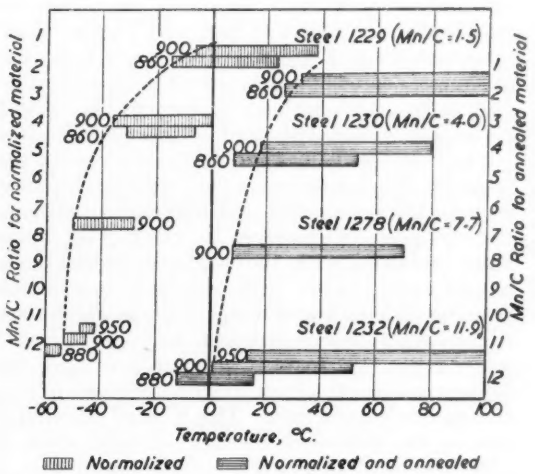



FIG. 27—Transition ranges (90% fibrous to 90% cleavage fracture) for steels of varying manganese/carbon ratio



XUM

TABLE III—*Mechanical Properties*

| Cast No. | Treatment | Yield Point, tons/sq. in. | Maximum Stress, tons/sq. in. | Yield Ratio, % | Elongation, %, on $4\sqrt{\text{Area}}$ | Reduction of Area, % |
|---|---|---|---|---|---|---|
| 1229 | Normalized 900° C. | 16·4 | 27·9 | 59 | 39 | 61 |
| | Annealed 900° C. | 13·7 | 25·7 | 53 | 37 | 56 |
| 1230 | Normalized 900° C. | 18·9 | 28·9 | 65 | 40 | 66 |
| | Annealed 900° C. | 14·0 | 26·7 | 53 | 37 | 61 |
| 1278 | Normalized 900° C. | 19·4 | 28·7 | 68 | 42 | 66 |
| | Annealed 900° C. | 15·8 | 26·3 | 60 | 38 | 64 |
| 1232 | Normalized 900° C. | 19·1 | 28·4 | 67 | 42 | 73 |
| | Annealed 900° C. | 16·0 | 26·4 | 61 | 41 | 63 |

Owing to the effect of initial structure and, more particularly, of the rate of cooling, a comparison of the transition range between steels in the "as rolled" condition may give very misleading results. This is well illustrated by steel 1232 which when annealed from 950° C. has a higher transition range than steel 1229 in the normalized condition.

### *Impact Values*

In the normalized condition, all the steels except 1229 (normalized 900° C.) give good impact values at 0° C. In the annealed condition, steel 1232 (annealed 880° C.), with the highest manganese/carbon ratio, gives the highest impact values at 0° and — 20° C., while steel 1229, with the lowest manganese/carbon ratio, gives the lowest impact values at these temperatures.

A notable feature of the results is that the curves showing impact values closely parallel the curves showing degree of cleavage. This parallelism was not evident with the tests on plates as described in the report of Barr and Tipper. With these high-frequency casts, variables, such as plate thickness, degree of rolling, directional properties, uniformity, and inclusions, present in testing plates are eliminated, and a truer comparison between impact values and degree of cleavage can be made. Impact values at 90% cleavage fracture, in both the normalized and annealed conditions, vary between 18 and 46 ft. lb., the highest values being obtained with the steels of highest manganese/carbon ratio. The impact values corresponding with the lowest temperature at which 100% fibrous fracture was obtained vary over a much wider range (167 to 74 ft. lb.) and here again the highest values are obtained with the steels of high manganese/carbon ratio. This is in all probability due to the increased ductility of these steels as shown by the elongation and reduction of area in the tensile tests (Table III). It is of interest to note that the yield ratios are also higher as the manganese/carbon ratio increases.

### SUMMARY AND CONCLUSIONS

Four high-frequency casts varying only in carbon and manganese contents and having approximately the same tensile strength, have been made. With these casts the effect of the manganese/carbon ratio on the mechanical properties, particularly the notch impact properties, of the steels in the normalized and annealed conditions have been investigated. The effect of the manganese/carbon ratio on grain growth and the effect of this grain growth on the notch impact properties have also been examined. From this work the following conclusions may be drawn:

(1) For a given tensile strength, increasing the manganese/carbon ratio of mild steel lowers the transition range in both the normalized and the annealed conditions.

(2) Increasing the manganese/carbon ratio tends to give a fine-grained steel as determined by the McQuaid-Ehn Test.

(3) Tendency towards grain growth is increased by a low manganese/carbon ratio.

(4) Increase in grain-size has the effect of raising the transition range, but unless the grain-size is abnormally large, the effect is slight compared to the effect of manganese/carbon ratio.

Structural steel for shipbuilding purposes has a tensile strength of 26–33 tons/sq. in., and is manufactured from steels with carbon contents of 0·12–0·24% and manganese contents of 0·35–0·7%. The manganese/carbon ratio varies from 1·5 to 4. It is evident from the investigations described that the higher the manganese/carbon ratio the better will be the impact properties under similar conditions of finishing temperature and rate of cooling.

A practicable recommendation would be that for shipbuilding steels the manganese/carbon ratio should not be less than 3·0.

# Some Factors Affecting the Notched-Bar Impact Properties of Mild Steel*

*By W. Barr, A.R.T.C., F.I.M.† and A. J. K. Honeyman, B.Sc., F.I.M.†*

SYNOPSIS

*Work carried out to confirm and extend conclusions stated previously by the authors on the influence of carbon and manganese on the notch sensitivity of mild steel is described.*

*Steels were made to carefully controlled compositions and their structures and impact properties in the normalized and annealed states were determined.*

*It was shown that increasing the carbon content raises the transition range and lowers the impact values of steels in the normalized condition, while increase of manganese content has the opposite effect.*

*It was confirmed that an increased manganese/carbon ratio tends to give a steel with a finer McQuaid-Ehn grain-size and a finer structure in the normalized condition. A comparison of steels made with and without a grain-controlling addition of aluminium showed that the manganese/carbon ratio may be as effective as grain-size control in reducing notch sensitivity.*

*A study of the relationship between the notched-bar impact value and the degree of cleavage in the fracture showed that the latter is not the best criterion by which to judge notch sensitivity. Material which gives a predominantly cleavage fracture will be satisfactory in service, provided that an appreciable amount of energy is absorbed before a crack is initiated.*

In the previous paper it was shown that for a given tensile strength (actually approximately 28 tons/sq. in.), increasing the manganese/carbon ratio of mild steel lowers the transition range in both the normalized and the annealed conditions. The results discussed were deliberately restricted to the single variable, manganese/carbon ratio, since the purpose of the report was to recommend practical and economical means of reducing the incidence of brittle fracture in mild-steel ship structures.

During and subsequent to this investigation, a number of other steels were examined and a more detailed study was made of the relationship between, and the significance of, notched-bar impact values and degree of cleavage in the fractures. This further work is discussed below and since it is closely linked with that already described, should be read as a continuation thereof. The table and figure references follow consecutively on those in the previous paper, hereafter referred to as Part I.

The high-frequency casts of which the analyses are shown in Table IV, were made in the same manner as those described in Part I. Normalizing and annealing treatments and mechanical tests were also carried out as before.

### *Microscopic Examination*

Structures of the steels in the normalized and annealed conditions are illustrated in Figs. 28–33. The A.S.T.M. (McQuaid-Ehn) grain-size was also determined. The results are shown in Table V, which also includes the Ac ranges and heat-treatment data.

### *Mechanical Tests*

The results of the tensile tests are recorded in Table V. Impact tests were also carried out and the degree of cleavage was determined as described in Part I. The results are shown in Figs. 34–36.

### *Consideration of Results*

#### *Effect of Carbon*

In Fig. 27, the effect of manganese/carbon ratio was shown in graphical form on the basis of the transition range, 90% fibrous fracture to 90% cleavage fracture. A more convenient method of comparing the steels is on the basis of that temperature which gives 50% cleavage in the fractures. In all cases, except Fig. 19 (annealed curve), this temperature coincides, or nearly coincides, with the maximum rate of change of the degree of cleavage. This temperature is also approximately in the middle of the transition range and if taken as the mean of the transition range, places the steels in the same order of merit. Accordingly, further discussion of results will be made on the basis of that temperature which gives 50% cleavage fracture. The results on this basis are shown in Table VI. (The last two columns in this table are discussed later.)

The effect of carbon on steels with low manganese content is shown by comparing steels 1228 and 1229. Increasing the carbon content raises the transition range and lowers the impact values

* Paper MG/106/47 of the Metallurgy (General) Division of the British Iron and Steel Research Association. Received 11th September, 1946.

† Messrs. Colvilles, Ltd., Glasgow.

TABLE IV—*Chemical Analyses of Steels 1228, 1231, and 1233*

| Cast No. | C, % | Si, % | S, % | P, % | Mn, % | Ni, % | Cr, % | Mo, % | Cu, % | Sn, % |
|---|---|---|---|---|---|---|---|---|---|---|
| 1228 | 0·10 | 0·14 | 0·035 | 0·013 | 0·30 | 0·03 | 0·03 | 0·025 | 0·035 | <0·01 |
| 1231 | 0·23 | 0·15 | 0·029 | 0·015 | 1·08 | 0·04 | 0·04 | 0·03 | 0·040 | <0·01 |
| 1233 | 0·21 | 0·14 | 0·028 | 0·014 | 0·82 | 0·04 | 0·04 | 0·025 | 0·035 | <0·01 |

at all temperatures in both the normalized and annealed conditions. A similar effect of carbon is shown with steels of high manganese content (1232 and 1231). These differences are partly due to the increase in tensile strength and consequent loss in ductility.

*Effect of Manganese*

The effect of manganese on steels of low carbon content is shown by comparing steels 1228 and 1232. Despite the increased tensile strength, the transition range is markedly lowered and the impact values increased at all temperatures in both the normalized and annealed conditions. At higher carbon contents also (*cf.* steels 1229 and 1230, and 1231 and 1233), increasing the manganese lowers the transition range.

*Effect of Grain-Size*

The McQuaid-Ehn grain-sizes of steels 1228, 1233, and 1231 confirm the conclusion that increasing the manganese/carbon ratio tends to give a finer McQuaid-Ehn grain-size. The microstructures illustrated in Figs. 28–33 confirm that increasing the manganese/carbon ratio also tends to give a finer ferritic grain-size in the normalized condition.

As is well known, the effect of aluminium additions, which render the steel fine-grained, is to lower the transition range. To determine the effect of aluminium on steels of low and high manganese/carbon ratio, two high-frequency casts of the composition and properties shown in Table VII were made. To one half of each cast an aluminium addition equivalent to 0·06% was made. The temperature/impact curves are shown in Figs. 37 and 38. Considering the manganese/carbon ratio of the steels without an aluminium addition the transition ranges are in agreement with what would be expected from Fig. 27 and Table VI.

The aluminium addition has lowered the transition range of both steels and in the case of the high-manganese steel the transition range has been lowered to a temperature below the lowest temperature used in this investigation. From the impact values it is probable that the transition temperature is approximately −80° C. It is of particular interest to note that the high-manganese steel of uncontrolled grain-size gives a lower transition temperature and higher impact values than the low-manganese grain-size-controlled steel, despite the fact that the latter has a finer ferritic grain-size. Also, there is little difference between the ferritic grain-size of steels 1261*B* and 1262*B*, although the former has a much lower transition range (Figs. 39–42).

*Notch Sensitivity*

The brittle (cleavage) type of fracture in mild steel has received considerable attention because, when failure occurs in ship structures, it has usually been characterized by cleavage fracture. The obvious remedy appeared to be to ensure that only plates which would not fail in this manner be employed. While this would certainly achieve its object, it is a much too drastic and quite

TABLE V—*Heat-Treatment and Mechanical Properties of Steels 1228, 1231, and 1233*

| Cast No. | A.S.T.M. (McQuaid-Ehn) Grain-Size | Treatment | Yield Point, tons/sq. in. | Ultimate Tensile Strength, tons/sq. in. | Elongation on $4\sqrt{\text{Area}}$, % | Reduction of Area, % |
|---|---|---|---|---|---|---|
| 1228 | 1–6 | Normalized 920° C. ... ... | 16·9 | 24·4 | 46 | 72 |
| 1228 | | Annealed 920° C. ... ... (Ac range 725–875° C.) | 13·8 | 22·3 | 47 | 71 |
| 1231 | 3–5 | Normalized 880° C. ... ... | 21·5 | 35·0 | 35 | 61 |
| 1231 | | Annealed 880° C. ... ... (Ac range 725–820° C.) | 18·7 | 32·8 | 35 | 57 |
| 1233 | 2–5 | Normalized 880° C. ... ... | 20·0 | 32·7 | 34 | 63 |
| 1233 | | Annealed 880° C. ... ... (Ac range 730–830° C.) | 17·2 | 30·4 | 35 | 57 |

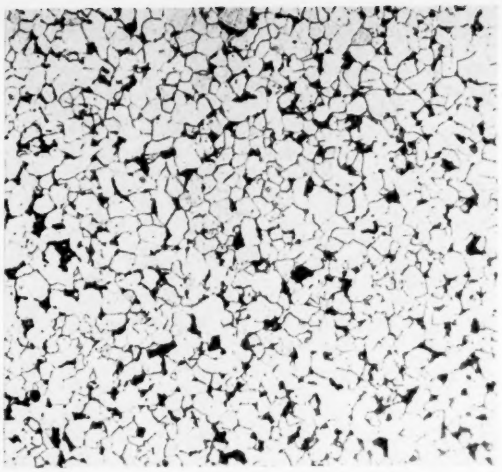


FIG. 28—Steel 1228, normalized. × 100

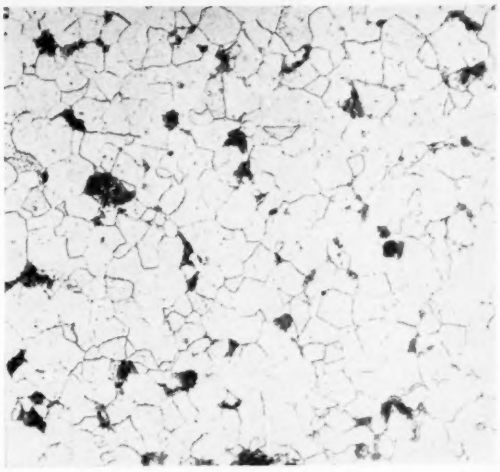


FIG. 29—Steel 1228, annealed. × 100

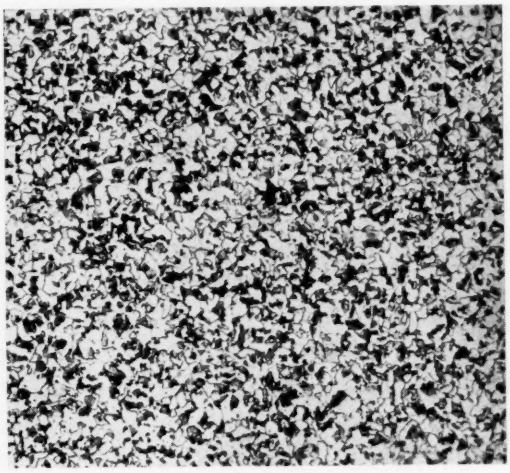


FIG. 30—Steel 1231, normalized. × 100

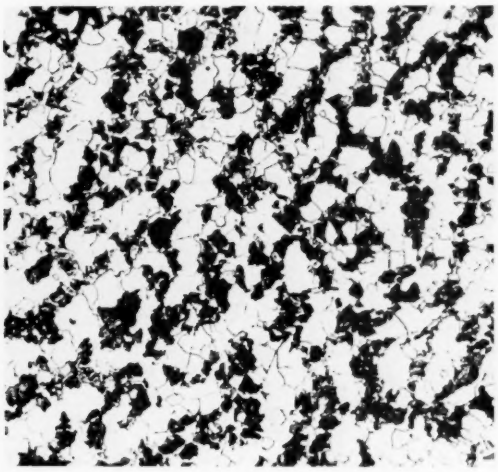


FIG. 31—Steel 1231, annealed. × 100

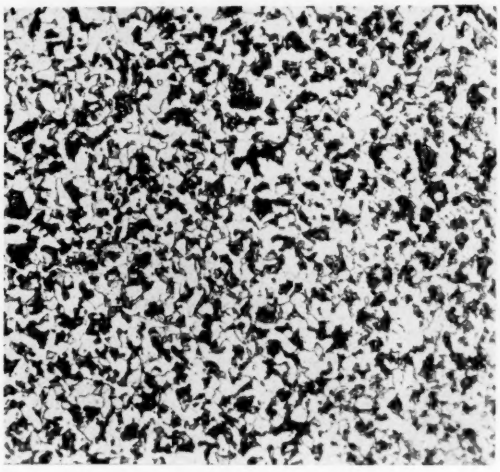


FIG. 32—Steel 1233, normalized. × 100

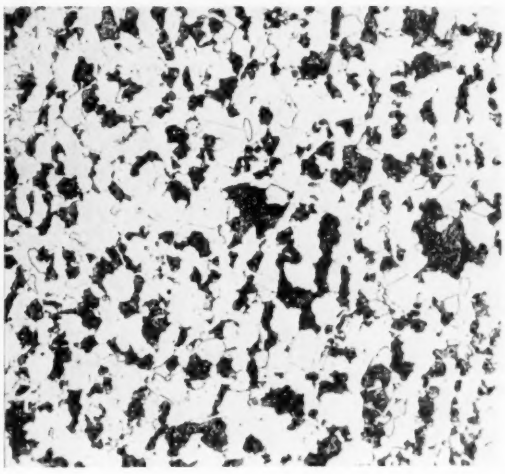


FIG. 33—Steel 1233, annealed. × 100

FIGS. 28–33—Microstructures of steels, etched in 2% nital

[*Barr and Honeyman*
[*To face p. 244*

XUM

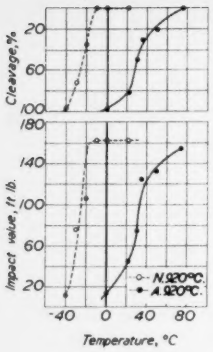



FIG. 34—Steel 1228

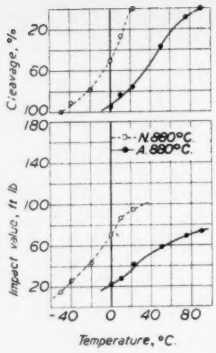



FIG. 35—Steel 1231

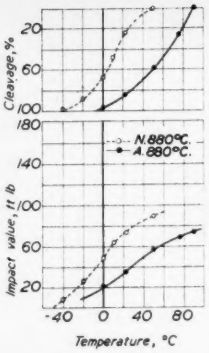



FIG. 36—Steel 1233

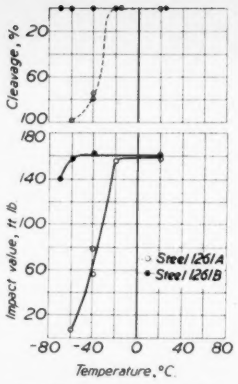



FIG. 37—Steels 1261 *A* and *B*, normalized

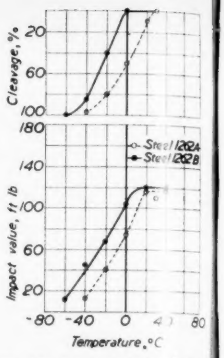



FIG. 38—Steels 1262 *A* and *B*, normalized

FIGS. 34–38—Transition ranges and impact values for the steels

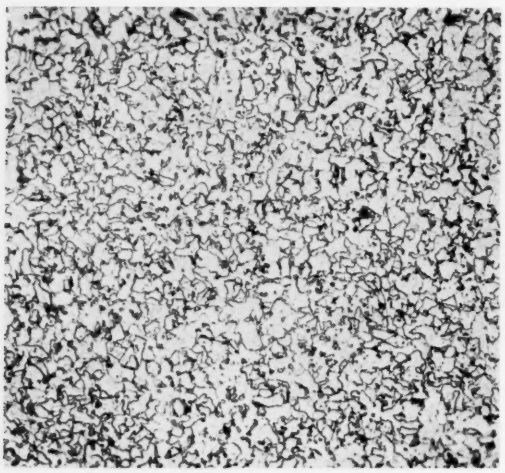


FIG. 39—Steel 1261 *A*, normalized. × 100

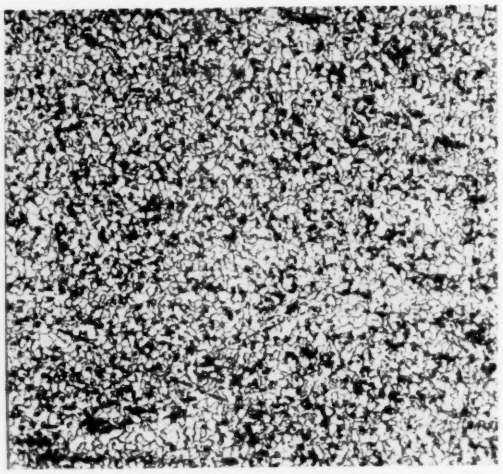


FIG 40—Steel 1261 *B*, normalized. × 100

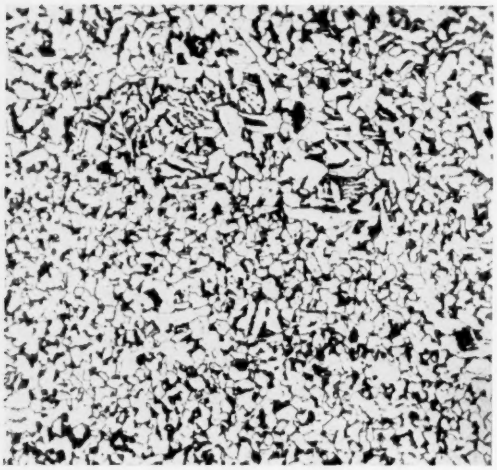


FIG. 41—Steel 1262 *A*, normalized. × 100

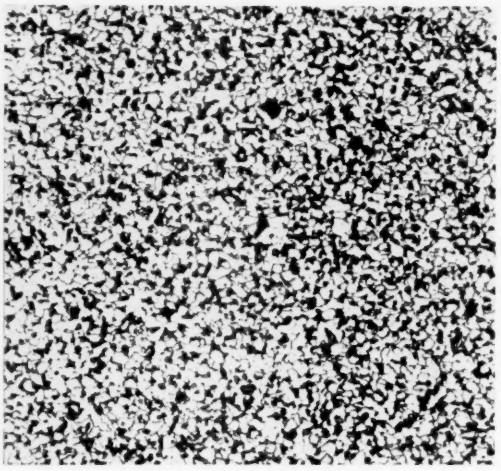


FIG. 42—Steel 1262 *B*, normalized. × 100

FIGS. 39–42—Microstructures of steels, etched in 2% nital

TABLE VI—*Transition Temperatures and Impact Properties*

| Cast No. | C, % | Mn, % | Mn/C Ratio | U.T.S., tons/sq. in. | Transition Temperature, ° C. | | Annealed Impact at 20° C. | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Normalized | Annealed | ft. lb. | Cleavage, % |
| 1232 | 0·10 | 1·19 | 11·9 | 28·4 | −50 | +25 | 70 | 65 |
| 1278 | 0·115 | 0·89 | 7·7 | 28·7 | −35 | +40 | 65 | 75 |
| 1228 | 0·10 | 0·30 | 3·0 | 24·4 | −25 | +30 | 40 | 85 |
| 1230 | 0·17 | 0·68 | 4·0 | 28·9 | −25 | +50 | 25 | 90 |
| 1231 | 0·23 | 1·08 | 4·7 | 35·0 | + 0 | +45 | 35 | 90 |
| 1233 | 0·21 | 0·82 | 3·9 | 32·7 | +10 | +60 | 30 | 85 |
| 1229 | 0·19 | 0·27 | 1·5 | 27·9 | +20 | +60 | 10 | 95 |

impracticable solution of the problem. It does not follow, and indeed it is contrary to experience, that the bulk of plates which give excellent service are of a "tough" nature. The great majority of ship plates are prone to brittle fracture once a crack has started, the degree of cleavage being of the order of 80%. What is required is not to ensure that fracture, when it does occur, is of a predominantly fibrous nature, but to ensure that a crack will not start. Stress raisers or notches of some form or other are always liable to be present, though good workmanship may reduce their incidence and good design minimize their effect. What then is required is that the steel should have a low notch sensitivity, that is to say, it should absorb a relatively large amount of energy before a crack is initiated. Material which shows a completely fibrous fracture in a notched bend or a notched-bar impact test has a very low notch sensitivity, but it does not follow that a steel which shows a high degree of cleavage in the fracture necessarily has a dangerously high notch sensitivity. It has not been possible to determine quantitative values for notch sensitivity and only a qualitative comparison under arbitrary test conditions can be made between different steels. This can be done by determining the energy absorbed up to the point at which fracture begins. Notched bend tests have shown that when the fracture is mainly cleavage, by far the greater part of the energy is absorbed before the crack begins. Since notched bend tests place steels in the same order of merit as does the notched-bar impact test, the latter is a convenient means of comparing the notch sensitivity of materials of which the fracture is predominantly cleavage, and this is an important property for ordinary mild steel of structural quality.

As was shown in Part I, higher impact values at 90% cleavage were obtained on the steels with higher manganese/carbon ratios. However, the temperature for 90% cleavage was different for the different steels and comparison of notch sensitivity should be made at the same temperature. At 20° C. all the steels gave predominantly cleavage fractures in the annealed condition; Table VI shows the impact values and degree of cleavage at this temperature. Except for 1230, the impact values at 20° C. place the steels in the same order of merit as does the transition range. Except for 1233, the degree of cleavage also places them in the same order, but covers a much narrower

TABLE VII—*Chemical Analyses and Mechanical Properties* of Steels 1261 and 1262*

| Cast No. | C, % | Si, % | S, % | P, % | Mn, % | Mn/C Ratio | A.S.T.M. (McQuaid-Ehn) Grain-Size | Yield Point, tons/sq. in. | Maximum Stress, tons/sq. in. | Elongation on $4\sqrt{\text{Area}}$ | Reduction of Area, % | Transition Temperature, ° C. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1262*A* | 0·175 | 0·16 | 0·030 | 0·010 | 0·43 | 2·5 | 2–5 | 18·8 | 28·6 | 40 | 64 | 0 |
| 1262*B* | 0·185 | 0·17 | 0·031 | 0·010 | 0·46 | 2·5 | Very fine | 21·6 | 29·6 | 42 | 67 | −25 |
| 1261*A* | 0·11 | 0·16 | 0·028 | 0·015 | 1·23 | 11·2 | 3–5 | 20·2 | 30·2 | 43 | 73 | −35 |
| 1261*B* | 0·12 | 0·17 | 0·023 | 0·015 | 1·27 | 10·6 | Very fine | 23·4 | 30·6 | 44 | 76 | <−70 |

* As normalized from 900° C.

TABLE VIII—*Notched-Bar Impact Strength of* A, D, *and* Z *Plates**

| Plate No. | Condition | Direction of Test | Charpy Impact Value, ft. lb. | |
|---|---|---|---|---|
| | | | 20° C. | 0° C. |
| *A*2 | As-rolled ... ... | L | 37 | 18 |
| | | X | 19 | 16 |
| *A*2 | Normalized 900° C.... | L | 50 | 32 |
| | | X | 28 | 20 |
| *A*3 | Normalized 850° C.... | L | 28 | 22 |
| | | X | 28 | 18 |
| *A*3 | Normalized 900° C.... | L | 24 | 13 |
| | | X | 24 | 9 |
| *A*3 | As-rolled ... ... | L | 25 | 12 |
| | | X | 16 | 9 |
| *D*1 | Annealed ... ... | L | 7 | 3 |
| | | X | 7 | 3 |
| *D*2 | Annealed ... ... | L | 6 | 3 |
| | | X | 6 | 3 |
| *D*2 | Normalized ... ... | L | 30 | 8 |
| | | X | 24 | 8 |
| *Z* | As received ... ... | L | 7 | $<5$ |
| | | X | 5 | $<5$ |

range of values. However, Barr and Tipper* demonstrated that "the extent to which the fracture is of the cleavage type is not always revealed by the impact value," and that "a high impact value may be accompanied by a fracture which is mainly cleavage." The results obtained on the production plates examined by them show clearly that the degree of cleavage in the fracture is not a satisfactory criterion of notch sensitivity for ship plates. For example, assuming a specification to state that at 20° C. a notch bend must show not more than 80% cleavage in the fracture, the plates listed in Table VIII would be rejected.

On the basis of practical experience, if plates of quality represented by *A*2 as-rolled, *A*2 normalized, and *A*3 normalized 850° C. were rejected, then probably 50% of mild-steel plates over ½ in. thick as supplied at present would be rejected.

Except in cases where there is something radically wrong with design, comparatively little yielding at a stress raiser would be sufficient to lower the stress concentration and so prevent the initiation of a crack. In other words, the notch sensitivity as determined by the notched-bar impact test is the proper criterion to apply. Just precisely what the required impact value should be is difficult to say, but experience of service failures in a wide variety of engineering structures indicates a modified Charpy or Izod impact value, at service temperature, of about 15 ft. lb., as being the limit below which there is real danger.

In specifying a minimum impact value this should apply to the minimum temperature likely to be experienced in practice. In the case of ship plates, if we accept 0° C. as the limiting service temperature, then the only plates of those under discussion which would fail would be *A*3 as-rolled, *A*3 normalized from 900° C., *D*1 annealed, *D*2 annealed, *D*2 normalized, and *Z*. In the case of the *A*3 plates, which may be taken as representative of normal production, normalizing at 850° C. has rectified matters. Of the plates which pass on the notched bend test, all have a minimum impact value of at least 18 ft. lb. at 0° C., except plate *D*1, which has a length impact value at 0° C. of 18 ft. lb., and a cross value of 14 ft. lb. Thus, the plates *D*1 and *D*2 should be rejected, since the manganese content is too low to permit of that margin of safety being obtained at 0° C., even after normalizing.

The foregoing discussion is not intended as a recommendation that an impact test form part of the specification for mild steel. Its primary purpose is to emphasize that too much importance may be attached to the fact that mild steel is prone to cleavage fracture in the presence of a notch. As already stated, the first essential is to avoid the presence of stress raisers and this is a matter concerning design and workmanship. So far as the quality of the material is concerned, the practicable recommendation already made that "for shipbuilding steels the manganese/carbon ratio should be not less than 3·0" is, in the light of our present knowledge and experience, an adequate safeguard.

### *Conclusions*

The following conclusions made in Part I, have been confirmed :

(1) Increasing the manganese/carbon ratio lowers the transition range in the normalized condition.

(2) Increasing the manganese/carbon ratio tends to give a finer grain steel as determined by the McQuaid-Ehn test.

The following further conclusions may be made :

(3) Increasing the carbon content raises the transition range and lowers the notched-bar impact values at all temperatures within this range.

(4) Increasing the manganese content lowers the transition range and raises the notched-bar values at all temperatures within this range.

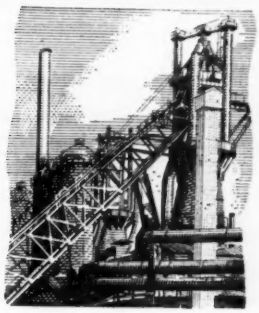
(5) A high manganese content may be as efficient as grain-controlling in lowering the transition range and increasing the notched-bar impact value, despite the fact that the grain-controlled steel may have a finer ferritic grain-size.

(6) The notched-bar impact test is a satisfactory method of indicating the notch sensitivity of mild steels of structural quality.

* W. Barr and C. F. Tipper, *Journal of the Iron and Steel Institute*, 1947, vol. 157, Oct., pp. 223–238.

IRON AND STEELWORKS ENGINEERING

THE IRON AND STEEL ENGINEERS GROUP



# Modern Small Rolling Mills*

*By G. A. Phipps†*

DURING the period 1932–1939 five small high-production mills, all of American design, were built and installed in Great Britain. The products of these mills are rods, bars, angles, strip, and merchant sections. Two of the mills were for the production of rods, one for strip, one for bar and strip, and the other for sections, bar, and strip. Although one or two small mills of German design were also installed during this period the general tendency has been to concentrate on American design and practice rather than the Continental. The author has, therefore, confined this paper to American types, with the object of indicating possible lines of future development in Great Britain of small merchant mills.

The subject of small modern mills (by which are meant mills having finishing rolls of 15-in. dia. and less, units of low operating cost, mills of high production per man employed, capable of meeting market demands as regards both quality and dimensions) is one that should be receiving the attention of the steel industry. In Great Britain, before 1939, there was always available a source of suitable labour to operate all types of rolling mills, whether the mill had the most efficient handling facilities or, as in the majority of mills, no mechanical aids, and required heavy manual effort on the part of the operatives. Stimulated by the fear of unemployment, there has been a rapid development of factories for the manufacture of producer goods, and for other types of light industry. Where these have been set up in steel-producing and re-rolling areas competition for labour is becoming a problem, and in about two years' time will have serious consequences to the steel industry, because of the inducements offered and the attractions of modern workshops operating under ideal working conditions. It should not be overlooked that the main reasons leading to the development of highly mechanized small mills in the U.S.A. were shortage of labour and a rapid expansion of demand, which hand-operated mills could not cope with, and the indications are that mechanization will have to be undertaken in this country for similar reasons. Another factor of major importance today is conservation of coal. The majority of furnaces for small mills in this country are operating at between 2·0 million and 2·6 million B.Th.U. per ton of finished output, whereas a modern high-production small mill actually operates at between 1·4 million and 1·7 million B.Th.U.

## A Two-Strand Rod Mill

Figure 1 shows a Morgan two-strand rod mill installed in this country in 1935. It will be seen that it comprises a billet skid bank, live roller gear to furnace, furnace-charging pinch rolls, a furnace having a hearth 32 ft. 0 in. wide and 30 ft. 0 in. long, a furnace pushout, a 7-stand continuous roughing train, a 3-stand intermediate train, 2 looping stands, a 7-stand finishing train, 4 laying reels, a coil conveyor, and a hook carrier. All the rolls are fitted with Morgoil bearings, so that the roll adjustments are only those required because of roll wear.

In Table I are the mill sizes, range, delivery speeds, and motor particulars.

The mill motors are supplied by a 2000-kW. motor-generator set, at a pressure of 500 V., and the 2900-h.p. synchronous motor operates on a 6600-V., 3-phase, 50-cycle supply.

It will be noted that the 7-stand roughing train

* Received 19th August, 1947.

† Messrs. Guest, Keen and Nettlefolds, Ltd., Cardiff.

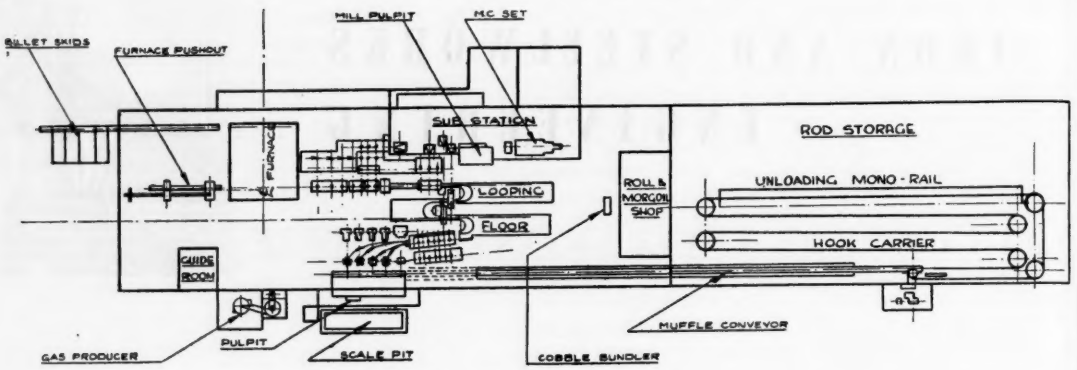



FIG. 1—Layout of rod mill

is driven by one motor, as are the intermediate train and the finishing train; hence the mill drafting is fixed within small limits by the mill gearing, with the exception of the two looping stands. Figure 2 shows the mill drafting for a 5-gauge rod. It will be seen that the first two stands are oval passes, followed by square and oval to the final round. Whilst this method of drafting gives the maximum reduction in the minimum of passes, the system is not suitable when a quality product of sound steel free from all types of rolling defects is required. This problem will be dealt with later in the paper.

The furnace was fired with raw producer gas from a single Morgan gas machine, until March, 1947, when because of the coal situation it was changed over to oil-firing. Ten burners are positioned across the width of the hearth and the change to oil was accomplished by inserting an oil burner in each of the gas burners. No alteration in the air supply to the furnace was necessary. During the period week ending March 22nd to week ending July 5th, 428,730 gal. of oil were burnt in the furnace, with 49,398 tons of good production from the mill, which on the basis of a mill yield of 95·5% gives the actual steel heated as 51,726 tons. The oil used per ton of steel heated works out at 8·29 gal. It will be appreciated that the furnace men had to be trained in the use of oil fuel, all burners being hand-controlled; if the system were adopted as a permanent feature with automatic control it is felt that the oil used per ton of output would be reduced by about 10%. During the period of oil firing all the mill production records have been broken. The record on one shift stands at 257 tons and during one 24-hr. period, in which the actual rolling time was 21·7 hr., 752 tons were rolled, involving two changes. The sizes produced were 2/OG, 3/OG and $\frac{5}{16}$ in. sq. The average production per shift is 182·2 tons, the best hour's production being 41 tons. Both are higher tonnages than have been obtained with producer-gas firing.

Notwithstanding the change enforced by present circumstances, during the period the furnace was on coal excellent results were obtained. In the year 1945–46, 8995 tons of coal were used at the producer, and the total tonnage of steel heated

TABLE I—*Details of the Two-Strand Rod Mill*

| Stand No. | Roll Dia., in. | Motor | | Delivery Speed, ft./min. | Rolled Sizes, I.S.W.G. (or in.) |
|---|---|---|---|---|---|
| | | h.p. | r.p.m. | | |
| 0–3 | $14\frac{1}{2}$ | 800 | 170–425 | | |
| 4–6 | $12\frac{3}{4}$ | | | | |
| 7–9 | $11\frac{1}{2}$ | 500 | 200–400 | | |
| 10–11 | 11 | 350 | 250–550 | | |
| 12 | 9·85 | | | 1370 | 4/0, 5/0, 7/0, and $\frac{17}{32}$–$\frac{9}{16}$ in. |
| 13 | 9·85 | | | | |
| 14 | 9·823 | | | 2300 | 1, $\frac{5}{16}$ in., 1/0, 2/0, 3/0, and $\frac{5}{16}$ in. square |
| 15 | 10·125 | 1250 | 450–750 | | |
| 16 | 10·36 | | | 3120 | 3, 2, 0·286 in., and $\frac{1}{4}$ in. square |
| 17 | 10·41 | | | | |
| 18 | 10·64 | | | 4000 | 6, 5, 4, 6 square, and 5 square |

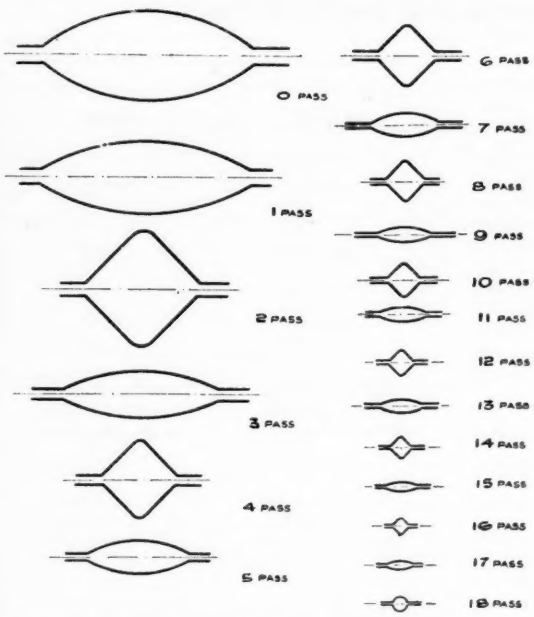



FIG. 2—Drafting of rod mill (2-in. billet to 5-gauge rod)

was 161,096, which is equal to 125 lb. of coal to heat 1 ton of steel. In the year 1946–47, 8293 tons of coal were used and 154,606 tons of steel were heated, *i.e.*, the amount of coal to heat one ton of steel was 120 lb.

Efficiency figures for the rod mill for the years 1945–46 and 1946–47 are given in Table II.

It will be noted that the miscellaneous stoppages during the period 1946–47 show a considerable increase over those in the period 1945–46 ; this is mainly accounted for by difficulties of coal supply and electrical load shedding.

In the year ending March, 1947, the electrical power consumed per ton of output for the mill and all auxiliaries, including cranes, pumps, etc., was 87 kWh., and for the mill drives only, 81 kWh. The average tonnage produced per shift of $7\frac{1}{2}$-hr. actual working time was for 5-gauge rod 170·5 tons, for 2-gauge 207·75 tons, for 2/0-gauge 213 tons, and $\frac{9}{16}$-in. dia. rod 252 tons. It will be appreciated that the above figures include the averages produced over $7\frac{1}{2}$-hr. actual working time, whereas the average per shift previously given includes roll-change times and all other classes of stoppages. Moreover, the main production from the mill is in 5-gauge, which accounts for approximately 50% of the total output, the remainder being split up over all other sizes.

The whole range of sizes is rolled during a period of a fortnight, and during one week of rolling the longest time to make a change is when altering the mill from 4 gauge to 3 gauge. This involves changing rolls 12–16, removing stands 17 and 18 from the mill, and changing passes in the two looping mills. The average time taken is 75 min. During the second week's operations, the change from 2 gauge to $\frac{17}{32}$-in. dia. is the longest ; it involves removing stands 8, 9, 13, 14, 15, and 16, dummy stands 5 and 6, and changing passes in stands 7, 10, and 11. The average time taken to do this is 105 min. It will be seen from Table II that roll-changing time per shift was 18·8 min. in 1945–46, and in 1946–47 the time was 20 min. per shift.

The analysis of manning per shift is indicated in Table III.

In this connection it is interesting to note that in 1944 the average output per employee, excluding inspectors, fitters, electricians, and mates, in tons per month was 64·6 ; in 1945 this figure had risen to 70·1, and in 1946 to 73·1.

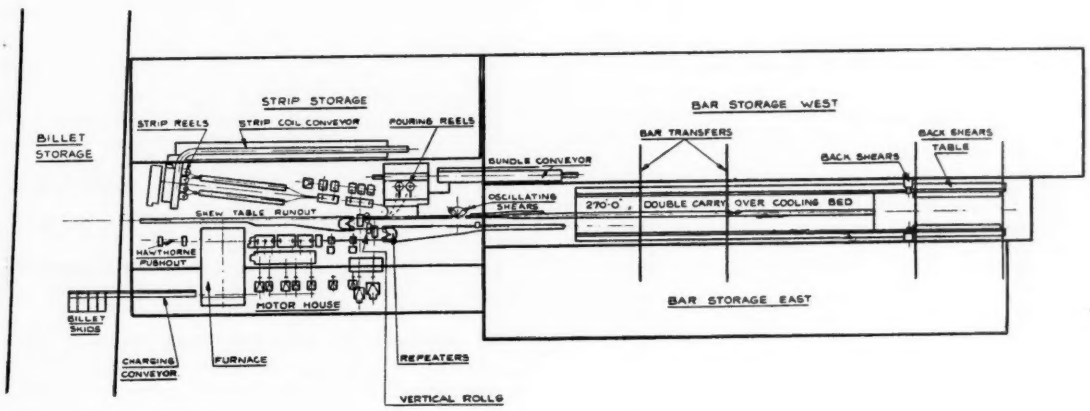



FIG. 3—Layout of merchant-bar and strip mill

TABLE II—*Rod-Mill Efficiency Figures for Years 1945–46 and 1946–47*

| | 1945–46 | 1946–47 |
|---|---|---|
| Total production, tons ... ... ... ... ... ... | 147,413 | 153,847 |
| Total number of shifts worked ... ... ... ... ... | 821½ | 863½ |
| Average number of shifts per week ... ... ... ... ... | 16·76 | 17·62 |
| Average output per shift, tons ... ... ... ... ... | 179·8 | 178·3 |
| Time occupied by roll changes ... ... ... ... ... | 258 hr. 28 min. = 32·3 shifts or 18·8 min./shift | 299 hr. 10 min. = 37·1 shifts or 20 min./shift |
| Time lost through mechanical stoppages ... ... ... ... | 34 hr. 31 min. = 4·3 shifts or 2·5 min./shift | 35 hr. 9 min. = 4·4 shifts or 2·4 min./shift |
| Time lost through electrical stoppages ... .. ... ... | 3 hr. 37 min. = 15·8 sec./shift | 8 hr. 50 min. = 1·1 shifts or 36·8 sec./shift |
| Time lost through miscellaneous stoppages ... ... ... | 58 hr. 25 min. = 7·3 shifts or 4·2 min./shift | 99 hr. = 12·5 shifts or 6·8 min./shift |
| Actual rolling time as a percentage of working time ... ... | 94·05 | 93·96 |

### A MERCHANT-BAR AND STRIP MILL

Figure 3 illustrates a Morgan merchant-bar and strip mill installed in 1939, which consists of 16 stands of roll housings, all 2-high, with vertical roll stands after both stands 9 and 10. It will be noted that in addition to a cooling bed for straight lengths, pouring reels are installed for the production of coiled bars up to 1 in. in dia. When rolling rounds, coiled or straight, and flats, 11 stands are used, and when rolling strip 5 additional stands (11–15 inclusive) are used. The products of the mill are as follows :

| Product | Size |
|---|---|
| Straight rounds | ½–1⅞ in. in dia. |
| Coiled rounds ... | ¹⁹⁄₃₂–1 in. in dia. |
| Flats ... ... | 5–1¼ in. wide × ⅜–¼ in. thick |
| | 4–1½ in. wide × ¾–⅝ in. thick |
| | 4–2 in. wide × 1–⅞ in. thick |
| Strip ... ... | 8⅛–7 ⁵⁄₁₆ in. wide × 0·176–0·080 in. thick |
| | 7¼–4¾ in. wide × 0·176–0·064 in. thick |
| | 4⅝–1⅞ in. wide × 0·176–0·047 in. thick |

These products are obtained from billets 2, 2¼, 2½, 3, and 3½ in. square × 30 ft. long, which are used for all the rounds and the narrower widths of strip and flats. The wider widths of strip and flats are obtained from slabs 30 ft. long and 2 in.

TABLE III—*Analysis of Manning of Rod Mill*

| Section of Mill | Number of Men Employed |
|---|---|
| Billet bank ... ... ... ... | 4 |
| Furnace and skids ... ... ... | 5 |
| Mill rolling ... ... ... ... | 14 |
| Roll shop ... ... ... ... | 3 |
| Guide room ... ... ... ... | 2 |
| Warehouse and stock bay ... ... | 24 |
| Cranes ... ... ... ... ... | 5 |
| Inspection ... ... ... ... | 4 |
| Fitters and mates ... ... ... | 6 |
| Electricians and mates ... ... | 2 |
| TOTAL ... | 69 |

TABLE IV—*Details of Motors and Rolls of Merchant-Bar and Strip Mill*

| Stand No. | Motor | | Roll Sizes, in. | Maximum Delivery Speed, ft./min. |
|---|---|---|---|---|
| | h.p. | r.p.m. | | |
| 0–1 | 500 | 720–240 | 16 $\frac{9}{16}$ dia. × 31$\frac{1}{2}$ | |
| 2 | 350 | 900–300 | 16 $\frac{9}{16}$ dia. × 31$\frac{1}{2}$ | |
| 3–4 | 700 | 900–300 | 14 $\frac{17}{32}$ dia. × 31$\frac{1}{2}$ | |
| 5 | 350 | 900–300 | 14 $\frac{17}{32}$ dia. × 31$\frac{1}{2}$ | |
| 6 | 350 | 900–300 | 14 $\frac{17}{32}$ dia. × 31$\frac{1}{2}$ | |
| 7 | 350 | 900–300 | 13 dia. × 24 | |
| 8 | 350 | 900–300 | 13 dia. × 24 | |
| 9 | 500 | 600–240 | 11$\frac{1}{2}$ dia. × 16 | |
| Vertical 9 | 36/14·1 | 1000–400 | 10$\frac{1}{2}$ dia. × 6 | |
| 10 | 500 | 600–240 | 11$\frac{1}{2}$ dia. × 16 | 1750 ft./min. |
| Vertical 10 | 36/14·1 | 1000–400 | 10$\frac{1}{2}$ dia. × 6 | |
| 11 | 2000 | 750–375 | 9·95 dia. × 12$\frac{1}{2}$ | |
| 12 | | | 10·19 dia. × 12$\frac{1}{2}$ | |
| 13 | | | 10·35 dia. × 12$\frac{1}{2}$ | |
| 14 | | | 10·55 dia. × 12$\frac{1}{2}$ | |
| 15 | | | 10·75 dia. × 12$\frac{1}{2}$ | 3050 ft./min. |

thick, ranging in width from 5 to 8 in. in increments of $\frac{1}{2}$ in.

Table IV gives the motor powers and speeds, roll sizes, and maximum delivery speeds of the finishing stands.

For the production of bars it will be noted that there are nine stands of rolls in tandem, followed by two open stands. From these latter two stands, bars and flats can either be run out on the skew transfer table, or, for all sizes of bars up to 1-in. dia., repeaters can be used. All rounds and flats are finished in stand 10 and straight lengths are run direct from the mill on live roller gear to the 270-ft. double-sided carry-over cooling bed. Positioned between the mill and the cooling bed is an oscillating disc shear to cut the finished product, $\frac{7}{8}$ in. or less in dia., into suitable lengths that can be accommodated on the cooling bed. One interesting feature of this mill is the provision of vertical rolls after stands 9 and 10, by the use of which excellent rounds of very low tolerance can be produced. These rolls are driven by vertical motors to which power is supplied from generators driven by the main mill motors of stands 9 and 10. By this means the speed of the vertical rolls is synchronized with that of the horizontal rolls. When rolling strip the stock is looped from stand 10 to the finishing train, and the strip is then carried through troughs which turn it on edge and enter it into pinch rolls for delivery on apron conveyors, at the end of which are four reels, and thence on to a strip-coil conveyor.

This mill can be rated as a high-production unit, as the figures in Table V for rounds and flats indicate.

The mill has operated under difficult conditions during the last three years, particularly as a result of shortage of billets. During this period it has only been possible to operate on two shifts. Furthermore, owing to frequent lack of supply of suitable billets, uneconomical rollings have often had to be undertaken.

In Table VI are the production figures for the last three years.

During the year ending March, 1947, when 81,123 tons of bars were produced, the electrical power consumed per ton of product was 49 kWh. for the mill and all auxiliary services, or for the mill drives only, 39 kWh.

In the same period the electrical power consumed per ton of output of strip for the mill and all auxiliaries was 74 kWh., and for the mill drives only, 56 kWh.

An average week's rolling of strip calls for 100–120 different sizes in gauge and width, and this accounts for the low percentage of working time to actual rolling time.

If an adequate supply of billets and slabs were available to operate the mill 17 shifts per week, the capacity on straight bars would be about 3400 tons per week and on strip 2500 tons per week. On the assumption that the mill operated two-thirds on bars and one-third on strip,

TABLE V—*Output of Merchant-Bar and Strip Mill*

| Size of Round, dia. in in. | Average Output per Shift, tons | Record Shift Output, tons |
|---|---|---|
| $\frac{5}{8}$ | 203 | 306 |
| $\frac{3}{4}$ | 226 | 321 |
| 1 | 249 | 298 |
| 1$\frac{1}{4}$ | 212 | 298 |
| 1 $\frac{9}{16}$ | 232 | 276 |
| Flats | 195 | 330 |



XUM

TABLE VI—*Production from Merchant-Bar and Strip Mill, 1945–1947*

| Year Ended | Production, tons | Shifts Worked | Average Production per Shift | Actual Rolling Time as Percentage of Working Time |
|---|---|---|---|---|
| | | *Bars* | | |
| March, 1945 | 76,430 | 408 | 187 tons 7 cwt. | 70·25 |
| ,, 1946 | 70,573 | 379 | 185 ,, 16 ,, | 76·93 |
| ,, 1947 | 81,123 | 474 | 171 ,, 1 ,, | 73·59 |
| | | *Strip* | | |
| March, 1945 | 14,375 | 96 | 149 tons 7 cwt. | 58·02 |
| ,, 1946 | 22,099 | 134 | 164 ,, 9 ,, | 64·73 |
| ,, 1947 | 29,950 | 190 | 157 ,, 0 ,, | 60·82 |

the annual output would be 112,000 tons and 40,000 tons respectively.

The mill motors are supplied with current from a motor-generator set comprising three 1260-kW. 500–250-V. generators, driven by a 4700-kVA. synchronous motor at 11,000 V., 3-phase, 50 cycles. The generators are arranged in two groups, *i.e.*, the five motors driving the roughing train are normally supplied by one generator, and the remaining motors are normally supplied by two generators run in parallel. The generators are designed to operate in parallel, whilst provision is made for coupling the bus bars so that all three, any two, or any one generator may be in service. This arrangement is very flexible and with the varying voltage allows the mill to be started at slow speed; when correct settings are obtained the speed of the mill as a whole can be raised by increasing the bus-bar voltage without changing the relative speeds of the stands.

An interesting feature of this mill is the furnace, which in the early part of this year was altered from producer-gas firing to firing by clean mixed coke-oven and blast-furnace gas at 240 B.Th.U./cu. ft., and fitted with automatic control gear. Figure 4 shows a diagrammatic arrangement of the automatic control gear for one zone, and also the gas and furnace pressure regulators. It is a well-known fact to operators of continuous mills of this type that the ideal heating condition is to have the front and back ends of the billets or slabs at a slightly higher temperature than the centre. With producer-gas firing, although the furnace men attempted to heat the billet in this manner, they very rarely succeeded, and even when the furnace was set to these conditions, they were almost impossible to maintain, except over a short period. In order to obtain the desired heating conditions full automatic control was fitted. This comprises an accurate pressure control of the gas

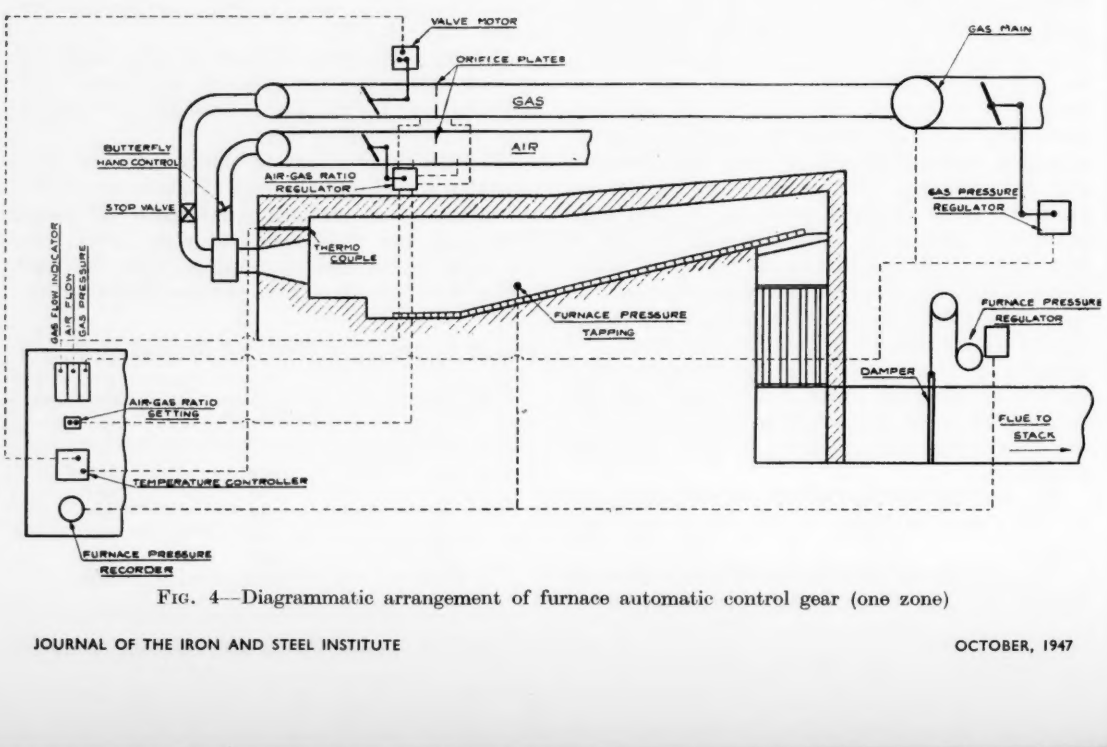



FIG. 4—Diagrammatic arrangement of furnace automatic control gear (one zone)

supply to the furnace, such that varying back pressures caused by the operation of control valves to some burners will not affect other burners. Since uniform temperature along the billet is not required and the burners are disposed along the length of the billet, the burners are grouped in zones, so that varying temperature conditions along the billet may be held, as required. Three zones are used, each containing three burners, and the gas to each zone or group of burners is fed from a manifold, each manifold being supplied by an individual gas main from the supply. In the main to each manifold there is an orifice plate which meters the gas to the zone and indicates the flow on the control panel. The impulse from this orifice plate is fed to the flow-ratio controller. The air mains to each zone are grouped in the same way as the gas mains, and each air main to a zone manifold contains an orifice plate, indicating air flow on the panel and applying it to the flow-ratio regulator, which is also receiving an impulse from the gas flow to that zone. This flow-ratio regulator is known as a gas/air ratio regulator, and operates a valve in the air main only.

In the gas main between the orifice plate and the zone manifold, is a butterfly valve operated by a motor and gear box, which gives floating and proportioning control from a temperature controller on the main panel. This controller measures the temperature of the zone in the furnace by means of a thermocouple inserted in the front wall of the furnace. It will be seen that a change of temperature in the furnace causes the temperature controller to move a valve in the gas supply main to the zone in question. The alteration caused in the rate of flow of gas is transmitted to the air/gas ratio regulator, which resets the air valve until the air flow is in the same proportion to the new gas flow, as it was before the change of temperature took place. All these changes are indicated or recorded on the control panel where there is also a set of push-buttons, which remotely operate the ratio of gas to air flow as required, enabling a reducing or oxidizing flame to be maintained in the furnace. The pressure in the furnace is recorded on the panel and transmitted to a furnace-pressure controller which operates the damper, maintaining the furnace pressure constant, whether the doors are closed or open for ejection of a billet into the mill, or when changes are taking place in the gas and air flows.

Although this system has only been in operation for a few weeks, it has fully justified the three-zone heating method and has proved that it is possible to produce previously established heating conditions, to control combustion conditions accurately, and also to reproduce combustion conditions.

The reason for the provision of pouring reels in the mill was a demand which commenced in 1939, and has since considerably increased, for coiled bars up to 1-in. dia., required in the manufacture of cold-headed bolts. This process calls for lightly cold-drawn stock, slightly below the diameter of the finished bolt, and from this size wire the bolt head is formed. It will be appreciated that this operation requires steel free from all defects, especially surface defects due to rolling. In the early days a certain amount of difficulty was experienced in obtaining a good yield of the product, which resulted in wide investigations as to the cause. One of the methods of checking this material is by what is known as a " slug " test, carried out in a hydraulic press. A specimen of the bar one diameter in length is compressed to 0·4 diameters in length. Failures invariably showed up on opposite sides of the bar, exactly 180° apart. They were traced to the mill drafting. Figure 2 indicates the oval/square method of reduction in the rod mill. This type of drafting was used in the roughing train of the bar mill. The main cause of the surface defects is the pinching which occurs at the root of the square pass when the oval is rolled into the square pass,

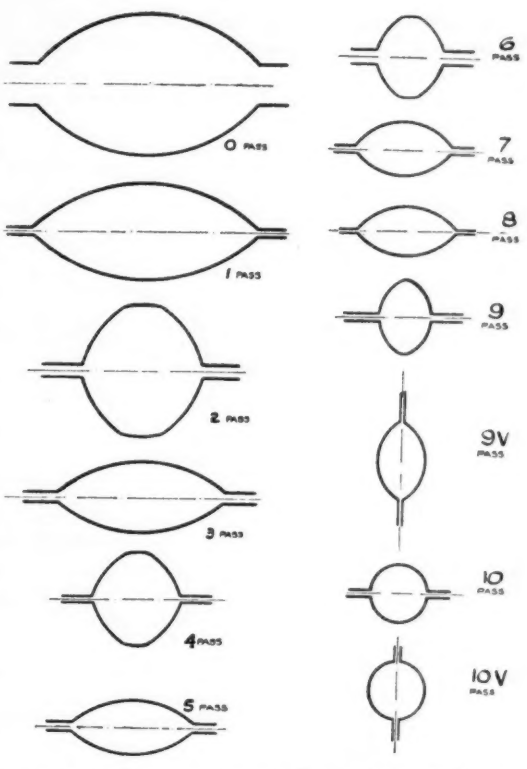



FIG. 5—Drafting of bar mill (2¼-in. billet to ¾-in. dia. bar)

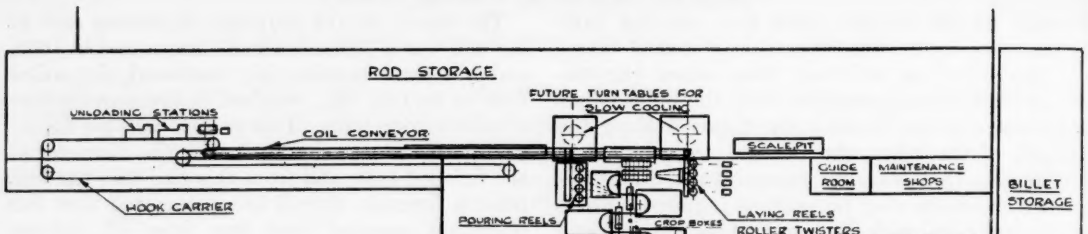



FIG. 6—Layout of bar and rod mill

and which, having once occurred, is still evident in the finished product. Figure 5 indicates the drafting as revised to overcome this difficulty. It is an oval-edging-oval method of reduction and entirely eliminates the pinching previously referred to, producing a bar free from the defects encountered with the oval/square method.

### A BAR AND ROD MILL

In 1946 consideration was given to a mill to produce all sizes of rods from 5 gauge upwards and coiled bars up to $1\frac{1}{32}$-in. dia. The mill had to have an output of 3750 tons per week of 17 shifts, when operating 9 shifts per week on 5- and 4-gauge rod, and also, by far the most essential condition, both rods and bars had to be produced free from all rolling defects and, in the case of bars, rolled to a close tolerance.

The tolerances on bars up to 1 in. produced in the bar mill previously described, were within the limits required, and the experience gained with the oval-edging-oval method of reduction proved that, provided the billets were free from defects, an excellent product could be rolled. The last important item was output, and bearing in mind that the weekly production of the

TABLE VII—*Details of the Bar and Rod Mill*

| Stand No. | Roll Dia., in. | Motor h.p. | Motor r.p.m. | Delivery Speed, ft./min. | Rolled Sizes, I.S.W.G. (or in.) |
|---|---|---|---|---|---|
| 0–1 | $16\frac{9}{16}$ | 200/200/130 | 900/300/195 | | |
| 2 | ,, | ,, | ,, | | |
| 3 | ,, | 300/300/195 | ,, | | |
| 4 | $14\frac{13}{16}$ | ,, | ,, | | |
| 5 | ,, | ,, | ,, | | |
| 6 | $13\frac{1}{8}$ | ,, | ,, | | |
| 7 | ,, | 350/350/227·5 | ,, | | |
| 8 | ,, | ,, | ,, | | |
| 9 | ,, | ,, | ,, | | |
| 10 | ,, | ,, | ,, | | |
| 11 | ,, | ,, | 600/200/130 | | |
| 12 | ,, | ,, | ,, | | |
| 13 | $11\frac{1}{2}$ | ,, | ,, | | |
| 14 | ,, | ,, | 750/250/162·5 | | |
| 15 | ,, | ,, | ,, | | |
| 16 | ,, | ,, | ,, | 2150 | $\frac{3}{8}$–$1\frac{1}{32}$ in. dia. |
| 17 | $10\frac{1}{6}\frac{1}{4}$ | | | | |
| 18 | $10\frac{1}{8}$ | | | | 1, $\frac{5}{16}$ in. dia., 1/0, 2/0, 3/0, and $\frac{5}{16}$ in. square |
| 19 | $10\frac{2}{6}\frac{5}{4}$ | 1750/1750/1138 | 835/600/390 | | |
| 20 | $10\frac{3}{6}\frac{5}{4}$ | | | | 3, 2, 0·286 in., and $\frac{1}{4}$ in. square |
| 21 | $10\frac{4}{6}\frac{1}{4}$ | | | | |
| 22 | $10\frac{22}{32}$ | | | 5000 | 5, 4, 6 square, and 5 square |

two-strand rod mill is about 3100 tons when operating on 17 shifts, the question arose whether to increase the number of strands to three or the delivery speed of the mill, when rolling the smaller gauges. The maximum delivery speed on similar-type mills in the U.S.A. was about 4400 ft./min. which was not fast enough to give the required production. Consideration was given to a delivery speed of 5000 ft./min. which was finally adopted, as it was felt that with careful attention to detail there was no reason why a rod mill should not operate satisfactorily at this speed.

Figure 6 indicates the layout of the mill which should be in operation towards the end of 1949. It will be noted that the usual billet feeding and discharge arrangements at the furnace are employed and that the mill layout comprises an 11-stand roughing mill, a 2-stand intermediate mill, a 4-stand looping mill, and a 6-stand rod-finishing train. Table VII gives the roll sizes, motor particulars, finishing-mill speeds, and dimensions of products.

It will be seen that sizes $\frac{3}{8}$–$1\frac{1}{32}$ in. in dia. are finished at stand 16 and delivered to pouring reels, from which the coiled bars are pushed out of the reels on to a coil conveyor, transferred to a hook carrier, and unloaded in the storage bay. The billet size for coiled bar is 3 in. square by 30 ft. long, and the finished coil is just under 900 lb. in weight.

Rod sizes are finished at stands 18, 20, or 22, delivered to laying reels and transferred to the storage bay in the same manner as coiled bars. For the rod sizes $2\frac{1}{4}$ in., billets 30 ft. long are used and the finished coils will weigh about 500 lb.

All sizes up to $\frac{23}{32}$-in. dia. will be rolled double strand and $\frac{3}{4}$-in. dia. and above single strand. The lowest output from the mill will be when rolling 5-gauge rod—about 28 tons/hr. When rolling $\frac{1}{2}$-in. dia. production will be 60 tons/hr., which is the rated capacity of the furnace. Production of diameters above $\frac{1}{2}$ in. will be limited by the maximum heating capacity of the furnace.

The furnace will have a hearth 50 ft. 0 in. long fired with mixed blast-furnace and coke-oven gases with a calorific value of 240 B.Th.U./cu. ft. Automatic control similar to that described and shown in diagrammatic form in Fig. 4 will be provided.

The experience with the rod-mill drafting (Fig. 2) and with the bar mill (Fig. 5) was utilized to provide what was considered to be the best method in the bar and rod mill. Figure 7 shows the type of pass design decided upon. It will be seen that pass 0 is a diamond giving only a light reduction ; it is followed by a diamond, a Gothic, and thereafter oval-edging-oval to pass 15. Pass 16 is a round followed by oval/round to the final 5-gauge rod. The maximum pass reduction

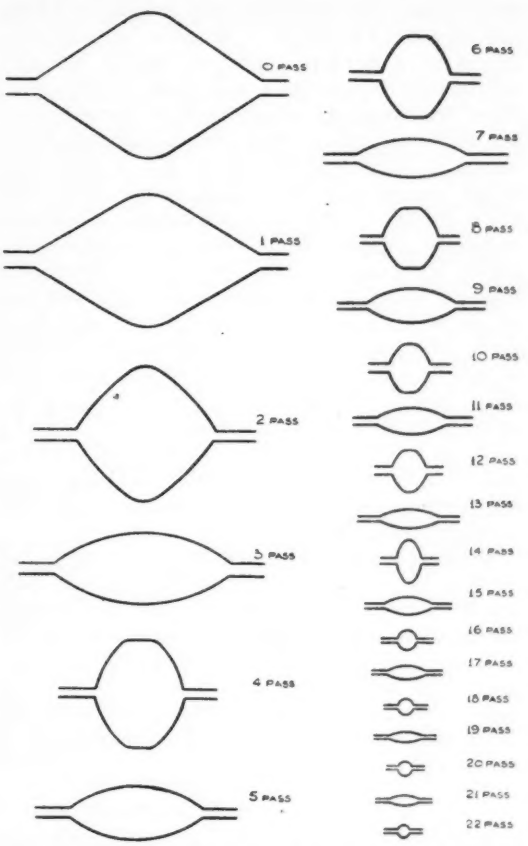



FIG. 7—Drafting of bar and rod mill ($2\frac{1}{4}$-in. billet to 5-gauge rod)

in Fig. 2 is 33%, and in Fig. 5, 26%, whereas in this bar and rod mill the maximum will be 26%.

Although it is the intention to roll low- and high-carbon and low-alloy steels, the mill is designed and motored to roll alloy and stainless steels, should these products be required in the future. For this reason provision is made to fit the slow-cooling arrangements for coils at a later date.

### A TYPICAL 12-IN. MILL

The mill indicated in Fig. 8 is typical of a number that are operating in this country, producing comparatively low tonnages, with lack of handling facilities for the adequate passage of the stock through the mill. The only aid to the operators is the live roller gear delivering the billets from the furnace to the roughing mill and taking the piece from the roughing mill to the three-high mill. It will be noted that the furnace is of the continuous pusher type and heats billets varying in $\frac{1}{4}$-in. increments from 2 to $3\frac{1}{2}$ in. square and 10 ft. to 11 ft. 6 in. long. A pusher ejects the billets from the furnace on to a live roller

gear feeding the roughing mill, which is 3-high and has rolls 14 in. in dia. × 4 ft. 0 in. barrel length driven by a 200-h.p. 490-r.p.m. motor through a reduction gear giving a mill speed of 140 r.p.m. From the roughing stand stock is carried on a live roller table to a cross train comprising three stands of 3-high rolls 12½ in. in dia. × 3 ft. 0 in. barrel length, and two 2-high stands with rolls 12½ in. in dia. × 16½ in. barrel length. This train is directly coupled to a 400-h.p. variable-speed motor operating at 110–250 r.p.m. From the finishing stand stock is delivered to a cooling bed of an inclined non-mechanical type, and from there on to roller gear to the shears for cutting to length. This mill produces rounds from ⅞ to 2½ in. in dia., flats from 1½ × ½ in. to 4 × 1 1/16 in., squares from ⅞ to 2 in., angles from 1½ × 1½ × 3/16 in. to 2¼ × 2¼ × ⅜ in., channels 3 × 1½ in., and 22-lb. bridge rails. In Table VIII are given the average and maximum tonnages per shift obtained from the mill.

With an improved furnace having an output of 12 tons/hr. the maximum production per shift would be increased to 90 tons, and the average tonnage per shift would be approximately 70–75.

It will be noted that when rolling 2 × 2 × ¼-in. angles the maximum tonnage per shift was 78½ tons, equivalent to 785 billets, and with the improved furnace the possible maximum is 90 tons, *i.e.*, 900 billets.

TABLE VIII—*Output of 12-in. Merchant Mill*

| Section | Size, in. | Tonnage per Shift: Average, tons | Tonnage per Shift: Maximum, tons cwt. |
|---|---|---|---|
| Rounds ... | Min. ⅞ | 47 | 64 18 |
| | Inter. 1½ | 62 | 72 0 |
| | Max. 2½ | 56 | 61 8 |
| Flats ... | Min. 1½ × ½ | 42 | 42 9 |
| | Inter. 2½ × ½ | 57 | 57 0 |
| | Max. 4 × 1 1/16 | 36 | 56 10 |
| Squares ... | Min. ⅞ | 64 | 73 15 |
| | Inter. 1 | 52 | 58 13 |
| | Max. 2 | 65 | 67 9 |
| Angles ... | Min. 1½ × 1½ × 3/16 | 57 | 68 9 |
| | Inter. 2 × 2 × ¼ | 72 | 78 10 |
| | Max. 2¼ × 2¼ × ⅜ | 55 | 55 0 |
| Channels ... | 4·6 lb. | 62 | 77 0 |
| Bridge rails | 22 lb. | 57 | 71 0 |

## A 13–10-IN. MERCHANT MILL

Figure 9 shows a 13–10-in. merchant mill which contains a number of interesting features. It will be noted that billets are transferred from the storage yard to the furnace by means of live roller gear, fed into the furnace by pinch rolls, and cross-pushed down the furnace. The latter has an inclined hearth, and at its delivery end a pusher feeds the heated billets into the mill. At the exit end of the furnace a shear is located to cut the billets in half, should the length of the finished section be longer than can be contained on the cooling bed. After the shear are four stands of rolls in tandem ; the first two stands have rolls 18 in. in. dia × 36-in. barrel length. driven by one 600-h.p. motor. The next two stands of rolls are 16 in. in dia. and 36 in. long, and are driven by another 600-h.p. motor. Following the tandem train there is a cross train of three stands of roll housings, the first two stands being 3-high, having rolls 13½ in. in dia. × 34 in. long, and the third stand being 2-high. with rolls 13 in. in dia. × 24 in. long ; the three stands are driven by one 1000-h.p. motor. On the same centre line as these three stands

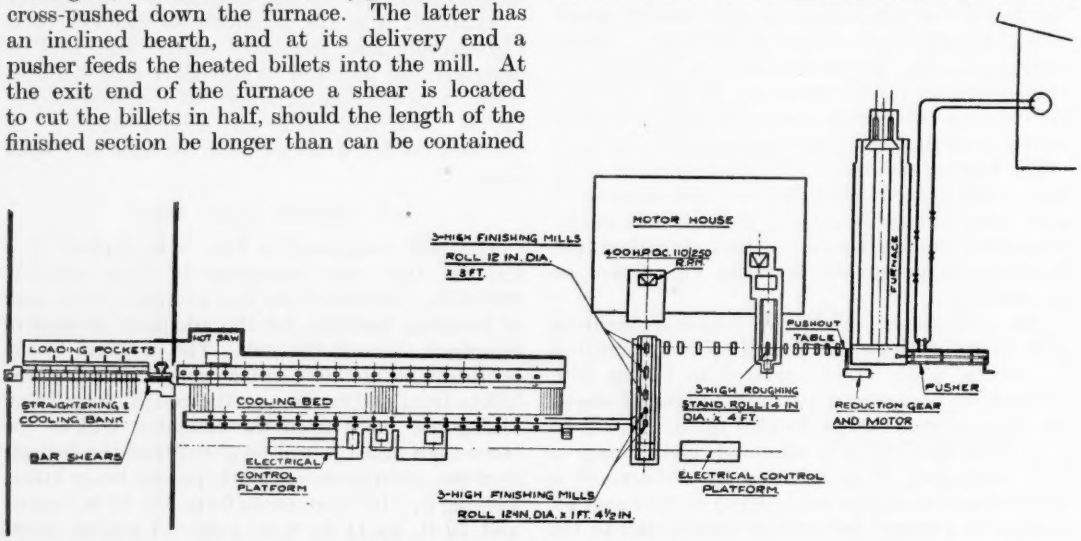



FIG. 8—Layout of 12-in. merchant mill

TABLE IX—*Details of Monthly Production of 13–10-in. Merchant Mill*

| | |
|---|---|
| Tonnage rolled... ... ... .. | 11,200 tons |
| Sizes rolled ... ... ... ... | 217 |
| Tonnage per size (average) ... ... | 51·7 tons |
| Sets of rolls changed ... ... ... | 131 |
| Number of sizes changed ... .. | 182 |
| Tons/hr. (average) ... ... .. | 21 tons |
| Average weight of section per ft. ... | 3·2 lb. |
| Total hours worked ... ... ... | 536 |
| Average time per change ... ... | 3·6 min. |
| Average time changing set of rolls ... | 18·6 min. |
| Total time lost in roll changing ... | 40 hr. 37 min. |
| Total time for size changes ... ... | 10 hr. 33 min. |
| Yield ... ... ... ... ... | 93·3% |
| Products rolled ... ... ... | Rounds, angles, flats, squares |

is a 2-high finishing stand for the larger sizes of product rolled; this stand has rolls $13\frac{1}{2}$ in. in dia. × 24 in. long, driven by a 500-h.p. motor, giving a roll speed of 150–300 r.p.m. In tandem with the latter stand are two more stands, having rolls $10\frac{1}{2}$ in. in dia. × 18 in. long, each driven by a separate motor of 500 h.p. and having speeds of 200–400 r.p.m. and 250–500 r.p.m. respectively. These last two stands are used for the smaller range of sections rolled. It will be noted that the mill floor on either side of the cross train is provided with roller gear and transfers for the manipulation of the stock between the stands. Beyond the 3-stand finishing mill the usual mechanical cooling bed, shears, etc., are provided. This mill produces the following:

(1) Angles 1 × 1 – 4 × 4 in.
(2) Rounds $\frac{1}{2}$–3 in. dia.
(3) Squares $\frac{1}{2}$–$2\frac{3}{4}$ in.
(4) Nut flats $\frac{3}{8} \times \frac{3}{4}$ in. and upwards
(5) Flats $1\frac{1}{4} \times \frac{3}{16} - 6 \times 1\frac{1}{4}$ in.
(6) Special sections for railway fastenings.

To deal with this production, billets ranging from $2\frac{1}{2}$ in. to $4\frac{1}{2}$ in. square and slabs $4 \times 3 - 6\frac{1}{2} \times 4$ in., all between 12 and 15 ft. long, are used. One of the features of this mill is the 3-stand tandem finishing train; all these stands are used for rounds up to $1\frac{5}{8}$ in. in dia. and any equivalent sections of other products. The sizes above $1\frac{5}{8}$ in. and equivalent are finished in the first stand of the tandem section. The drafting on these last three stands is round, oval, round, respectively, thus obviating a twist in the stock, except between the oval and finishing stand. Positioned between the tandem finishing stands are looping troughs which can be withdrawn sideways from the mill to allow access to the roll stands. These troughs are split down the centre and open about their centre line, the operation of opening and closing being automatic and controlled by the load on the exit motor. The average production per month of this mill is 11,200 tons. The analysis of a typical month's production is given in Table IX.

It will be noted that the average tonnage per size rolled was 51·7; it is claimed that an economical tonnage to roll and change for is 45 tons. Only under special circumstances will the mill be changed for less than this amount.

## A 12-IN. MERCHANT MILL

Figure 10 shows a 12-in. merchant mill. It will be seen that the mill has two continuous furnaces, each with inclined hearths 17 ft. wide × 50 ft. long. A pusher at the rear of the furnace traverses the billets down the hearth and they are ejected from the furnace by power-operated bars on to an inclined table and delivered on to live roller gear. A shear is positioned in the roller table for cutting billets into two equal parts, so that the finished section is not more than the length of the cooling bed. Beyond the shear is a 2-high stand of rolls used only for scale breaking, hence a single pass only is taken here. In tandem with the scale breaker is the 3-high roughing mill with rolls $16\frac{3}{4}$ in. in dia. and of 54-in. barrel length, with independent motor drive. At the rear of the mill is a power-operated

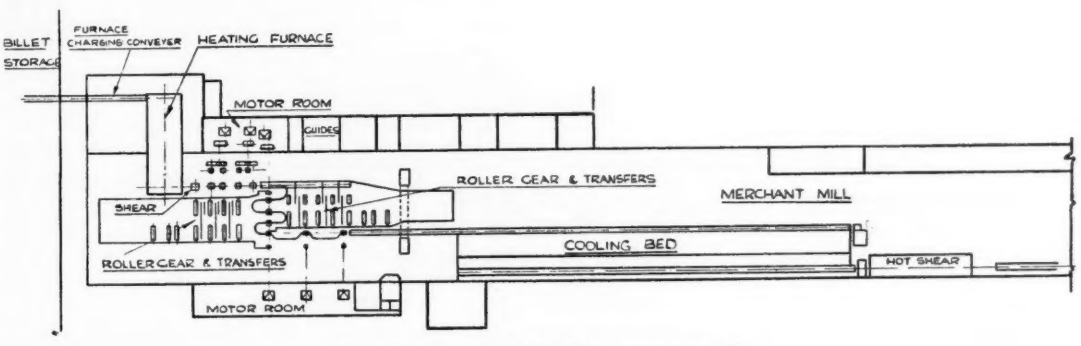



FIG. 9—Layout of 13–10-in. merchant mill



XUM

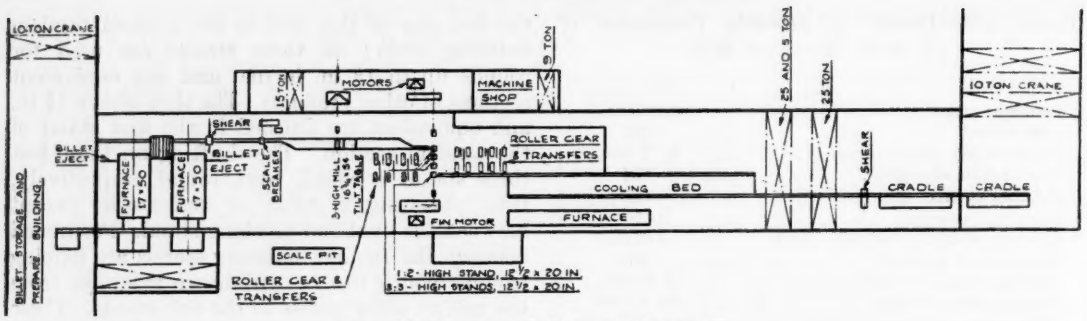



FIG. 10—Layout of 12-in. merchant mill

tilting table with manipulator. In line with the delivery pass from the roughing mill is the first stand of a 3-stand 3-high cross train, each stand having rolls 12½ in. in dia. × 20 in. long; these stands are driven by one motor. In line with them is a single 2-high finishing stand with rolls 12½ in. in dia. × 20 in. long, with individual motor drive. At the front and rear of the four stands of rolls of the cross train are live rollers with skid transfers for manipulating the piece to and from the rolls. In line with the finishing stand is a cooling bed of the carry-over type, 225 ft. long, with the usual shears, etc. Adjacent to the cooling bed is a furnace used for slow-cooling alloy steels of the air-hardening type. When rolling this class of steel, overhead cranes transfer the sections to the furnace immediately they are delivered on to the cooling bed.

All sections produced in the mill are rolled from either 4 or 5 in. sq. billets from 10 to 15 ft. 0 in. long, with, as previously mentioned, provision for shearing the billets into shorter lengths, if necessary. The range of sections rolled in the mill is as follows:

| | | |
|---|---|---|
| Rounds | ... | $1_{6}^{7}/_{4}$–2½-in. dia. |
| Flats | ... | 2–4 in. wide, ¼–1¾ in. thick |
| Squares | ... | $^{19}/_{32}$–2¼ in. |
| Angles | ... | 1¾ × 1¾ in. and 2 × 2 in. by ⅛–⅜ in. |

In an 8-hr. shift rolling 2½-in. rounds, using 5-in. billets weighing 1250 lb. the mill has produced 485 finished tons, an average of nearly 61 tons/hr. This requires 970 billets to be handled through the mill, or an average of 121 billets/hr. When rolling 1⅝-in. dia. rounds, 335 finished tons have been rolled in a shift from 4-in. billets weighing 735 lb. (in this case over 1100 billets were rolled). Production of 1⅛-in. rounds is about 275 tons per shift.

The outstanding feature of this mill is the 3-high roughing stand. Here the majority of sections rolled are given five passes and two pieces are always in the mill.

### A 15-IN. MERCHANT MILL

Figure 11 illustrates a 15-in. merchant mill of the "cross-country" type. An interesting feature of this mill is that it is fitted with a special die-rolling stand for the production of forging blanks. It will be noted that the usual method of charging the billets into the furnace is adopted, and that the furnace is of the inclined-hearth type, 60 ft. long, and takes a 30-ft. long billet. The furnace is fired with coke-oven gas and crude oil, the burners being arranged alternately, coke-oven gas and oil, across the width of the furnace at the push-out end. High outputs are claimed

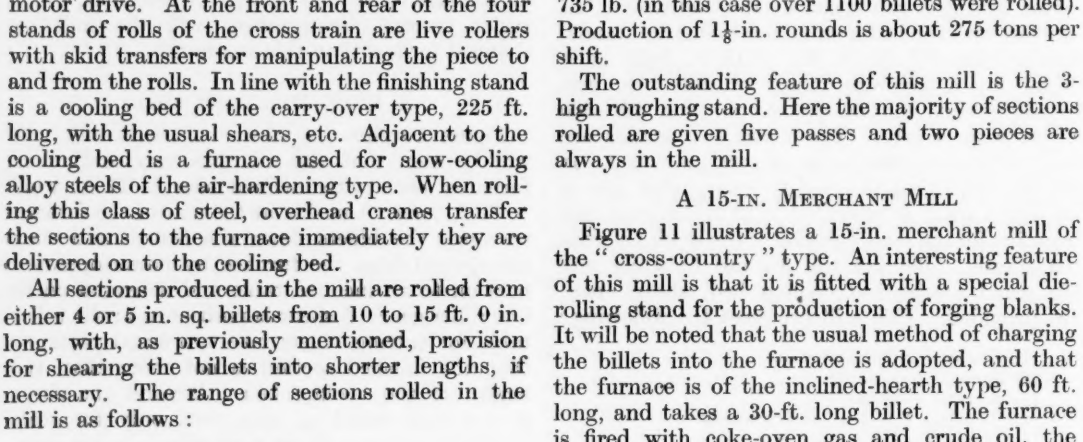



FIG. 11—Layout of 15-in. merchant mill

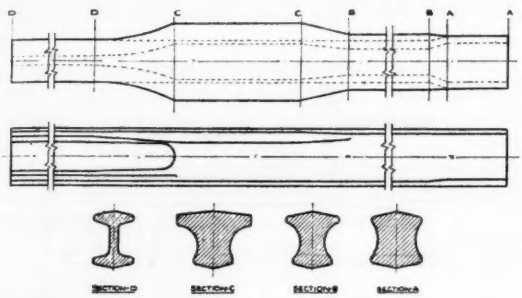


FIG. 12—Typical die-rolled section

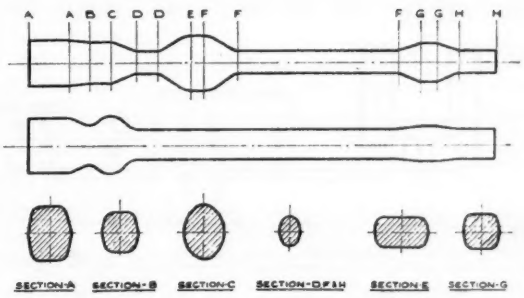


FIG. 13—Typical die-rolled section

for the furnace, attributed mainly to the method of firing, and continuous runs of 85 tons/hr. have been obtained, when heating blooms 7 in. × 6 in. × 30 ft. long. With top heating the heat penetration is 6 in., and when heating at a rate of 85 tons/hr., the difference in temperature between the top of the bloom in contact with the gases, and the bottom of the bloom is only 22° C.

It will be seen that at the exit end of the furnace a shear and pinch rolls are installed, followed by three stands of 2-high rolls in tandem, a length of live roller gear, a further 2-high stand, and a 3-high stand. From the latter the piece is delivered "cross-country" to a further 3-high stand, hence into either the die-rolling stand or the two-high finishing mill stand, and then to the cooling bed.

The normal sections produced in the mill are rounds of $1\frac{7}{16}$–$5\frac{1}{2}$-in. dia., squares $1\frac{1}{8}$–6 in., flats $3 \times \frac{3}{8}$–$8 \times 2\frac{1}{4}$ in., and flats of less than 3 in. but having a cross-sectional area of more than 1·125 sq. in. The maximum output obtained from the above range of sections is 35 tons/hr. for the smaller sections, and up to 85 tons/hr. for the larger sections.

In the die-rolling stand the rolls used vary from $15\frac{3}{4}$ to $32\frac{1}{2}$ in. in dia., depending on the type of section required. The rolls are in the form of steel sleeves mounted on mandrels. The mill is driven with conventional-type universal spindles and pinion housing, which cater for all the diameters of rolls used in the mill. A wedge coupling is fitted to the top spindle at the pinion housing end, to mate the rolls correctly. It will be appreciated that accuracy of roll setting is most important, hence only a minimum of wear of the phosphor-bronze slippers in the universal spindles is permissible.

Figure 12 illustrates a typical section rolled on the mill. This is an axle for a light lorry. The four sections indicated have reductions of approximately 70%, 28%, 48%, and 36%, respectively.

Figure 13 indicates another type of section rolled in which the reductions vary from 0 to 75%. All the reductions mentioned take place in this one stand, hence heavy fins or flashes are formed on those parts of the section where heavy reductions take place. In the case of complicated sections, particularly those with heavy fins, only a small tonnage can be rolled per pass, and in some cases only 700–800 tons of product can be obtained per pass for the life of the roll. When simple types of pre-formed section are rolled, a tonnage of 10,000–15,000 tons can be obtained per pass.

### A 14-IN. "CROSS-COUNTRY" TYPE OF MERCHANT MILL

Figure 14 illustrates a "cross-country" type of merchant mill with finishing rolls 14 in. in dia. This mill has two continuous furnaces capable of heating billets from 4 × 4 in. to 7 × 7 in. by a maximum length of 15 ft. 0 in., at the rate of 100 tons/hr. Billets are pushed out from the furnace on to live roller gear for delivery to stand 1 of a 6-stand semi-continuous roughing train, the first four stands having rolls 20 in. in dia. and the last two stands having rolls 18 in. in dia. All these stands are driven by a 3500-h.p. motor. Stand 7 is in line with the semi-continuous roughing train and has rolls 16 in. in dia., the same size rolls being used in stand 8; these two stands are driven by a 1250-h.p. motor. Stand 9 has rolls 14 in. in dia. and is driven by a 900-h.p. motor. The 3-stand finishing mill comprises two stands of horizontal rolls 14 in. in dia. × 24 in. long and one stand of vertical rolls 15 in. in dia. positioned between the horizontal stands. Live roller tables are provided at the roll stands and transfer tables between stands 6 and 9, stands 7 and 8, and also between stands 9 and 10. It will be noted that a repeater can be used between the latter two stands for the smaller sizes of product. From stand 12 live roller tables deliver the finished product to a double-sided carry-over type cooling bed with the usual shears and auxiliaries.

The main feature of this mill is the 3-stand continuous finishing section, vertical rolls obviating twist between the passes and reducing guide scratching to a minimum. Furthermore, a higher

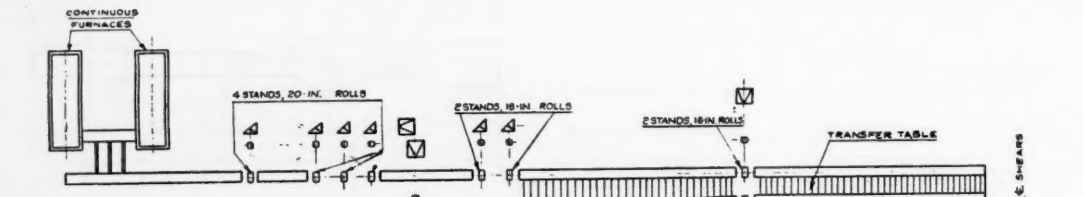



FIG. 14—Layout of 14-in. merchant mill

finishing speed is possible, resulting in higher production and an accurate product.

When rolling 1-in. dia. rounds a production of 60 tons/hr. can be maintained throughout a shift. Over a period of one month this mill has rolled 39,500 tons, and the average weight of section over the period was 9 lb./ft. This figure is a mill record, but average monthly production is between 33,000 and 35,000 tons.

## CONCLUSIONS

### *Rod Mills*

Two rod mills have been described, one of which, although still in the drawing stage, will be an improvement on all the rod mills in the U.S.A. operating more than one strand. In Great Britain, there will then be five rod mills, including the one projected, all modern efficient plants producing the majority of rods rolled in the United Kingdom, so it would appear that this country is well provided with this type of mill.

Whilst no previous mention has been made of straight length bars $\frac{1}{4}-\frac{7}{16}$ in. in dia. it cannot be overlooked that production of these sizes, which are required in considerable tonnages for reinforcing and bolt bars, has been a problem for a number of years. The extras on these sizes do not compensate for the low productions obtained when rolled in straight lengths single strand, the conversion cost being excessive. The solution to this problem obviously lies in rod mills. The sizes can be produced in two or more strands simultaneously, at the production rate, in a two-strand mill, of 180–220 tons per shift, as against 20–80 tons on single-strand mills producing straight lengths. Moreover, when rolling straight lengths only a short length can be rolled, whereas a heavyweight coil is produced in a rod mill, with consequent higher yield. The processing of coils in straightening and cutting-off machines is an additional cost on this method of production, but the ultimate total cost is less and in the author's opinion this is the only economical method of production of these small sizes.

### *Narrow Strip Mills*

Only one narrow strip mill has been described, but there are five modern narrow strip mills, covering a range from 2 to 9 in. wide, producing heavy weight coils about 200 lb. weight per inch of width ; two of them are combination mills. These five mills produce a high percentage of the total production of Great Britain and can be considered efficient production units, having low conversion costs.

### *Merchant Mills*

From the conclusions reached regarding both the rod and narrow strip mills, it will be seen that the country is well equipped with such mills, running at low conversion costs and high shift outputs. The same cannot be said for merchant mills, there being only four high-production mills operating with 11–12-in. finishing rolls, and of these only one is regularly producing small structural sections.

In the range of mills having finishing rolls 13–15 in. in dia., there is not one in this country that can be deemed modern. It would appear, therefore, that development of mills of this range is long overdue.

The mills described in this paper, and illustrated in Figs. 9, 10, 11, and 14, are mills designed and operated in America. These mills have outstanding features, and are indicative of the possible lines of development which could with advantage be followed here.

The typical British merchant and section mill illustrated in Fig. 8 is underpowered, has no mechanical aids, and uses seven billet sizes to cover the production range.

A similar type and size of mill is that illustrated in Fig. 10, but here all the mechanical aids for

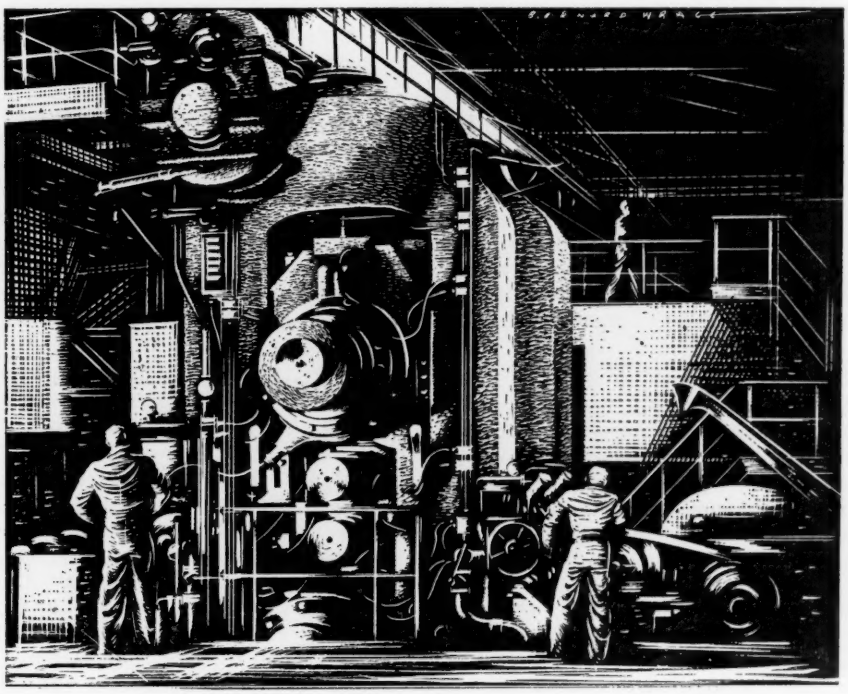
high production have been provided, and only two billet sizes are used. When rolling 2½-in. dia. rounds, the American mill, using 5-in. sq. billets, rolled 485 tons per shift of 8-hr. working time, whereas the British mill has produced a maximum of 61 tons per shift, from a 3½-in. sq. billet. Similar comparisons can be made throughout the production range, although for the lighter sections, the difference is not so pronounced.

The mill shown in Fig. 9, probably with modification to detail, but retaining the main features, has decided possibilities. The 3-stand tandem finishing train considerably widens the range of products, whilst maintaining high production on smaller sizes. Furthermore, higher delivery speeds are obtained from the tandem train, the stock entering the first stand, being fed in at maximum speed for manual handling, whilst the delivery speed from the final stand is considerably higher.

It would appear that the mills in Figs. 11 and 14 are entirely unsuitable for operation in this country, but they have been included to indicate the productive possibilities of small mills, when comparatively large tonnages of a size are required.

### *General*

The author is of the opinion, based on a study of the best features of all the types of mills discussed, and suitable for the trade requirements of this country, that there are a number of possible mill layouts, for overall weekly outputs of 2000 to 2500 tons, which can be economically operated, if a minimum of say 40 to 45 tons of one size is rolled.



# MECHANICAL AND ELECTRICAL FEATURES OF PRIMARY HOT-ROLLING-MILL AUXILIARIES*

*By W. W. Franklin and P. F. Grove*

## SECTION I—MECHANICAL FEATURES

*By W. W. Franklin, A.M.I.Mech.E.*†

With the advance of rolling-mill design to meet the ever increasing demand for output and continuity of production, the mill auxiliary machinery, together with its electrical equipment, has also been progressing in design to keep abreast of the mill itself. It cannot be claimed that any one item of the mill auxiliaries is the keystone of the whole plant, since the breakdown of any individual piece of equipment may shut down the entire mill. Similarly any single auxiliary if not designed to deal with the output capacity of the mill will obviously impede that output.

There are certain items of plant on which opinions differ widely as to the most suitable construction to be employed, and the object of this paper is to present various alternatives for several such auxiliaries, with the expectation that opinions will be freely voiced so that we may all learn of operators' difficulties with any particular design and that suggestions will be made for the mutual benefit of equipment builders and operators.

The authors have limited the scope of this paper to such auxiliary machinery as they believe will have the most general field of interest and have, therefore, confined themselves to examples of heavy hot-mill equipment, leaving the wide range of specialized machines to be found in the hot and cold production of sheet, strip, plate, etc., as demanding a paper devoted entirely to these items.

### Roller Tables

Mill tables perform a very essential function on any rolling mill and must be designed according to the duty that they have to carry out. This duty varies considerably on different types of mill and different sections of the same mill. A considerable proportion of the tables merely performs the duty of transporting the rolled stock and their design is comparatively simple. Other tables such as the ingoing and outgoing main tables of a blooming mill have to withstand heavy shock loads when receiving an ingot from the mill and when the ingot is being turned over by the manipulator. The tables must be capable of rapid and frequent reversals and are subjected to considerable heat. It frequently occurs that an operator in order to step up production maintains the rollers running into the mill, in effect giving a "braking" action to the ingot so as to ensure a quick return for the subsequent pass. The table, while running in one direction, is called on to receive an ingot or bloom being driven in the opposite direction by the mill rolls.

The main tables, therefore, present more problems to the designer than other tables and for this reason it is proposed to make them the basis of this discussion.

In addition to legislating for the duties above mentioned the designer must give careful attention to initial cost, ease of assembly, and maintenance.

Two modern designs of tables will be described :

(1) Tables with roller bearings.

(2) Tables with oil-lubricated plain bearings.

#### *Common Features*

Obviously certain features of design and construction will be common to both types, but the principles of each have their own problems.

Let us consider first the principles common to both designs :

The table rollers are solid steel forgings usually 18 in. to 20 in. in dia. and pitched at the minimum possible centres, usually around 2 ft. 6 in., consistent with the accommodation of the guides and fingers of the manipulator. This spacing is a difficult problem when a short ingot is to be dealt with and compromises have to be arrived at to reduce the roller centres to the minimum to ensure that the ingot is efficiently handled on the table.

The level of the top of the rollers relative to the pass line of the mill rolls needs careful study and no hard and fast rule can be laid down ; it is determined by the type of mill, the section to be rolled, and the normal maximum draft taken. It will be obvious that severe shock loads can be imposed on the rollers by the piece leaving the mill if the roller level is too high or, conversely, difficulty will be found in entering the mill bite if the level is too low.

The table frames are rugged steel castings strongly tied together and designed to accommodate the mill manipulators. Bevel gears should be of forged steel with machine-cut teeth. The main reduction-gear drive, designed for heavy reversing duty, has the second gear split to give

* Received 13th August, 1947.

† Chief Engineer, Davy and United Engineering Co., Ltd., Sheffield.

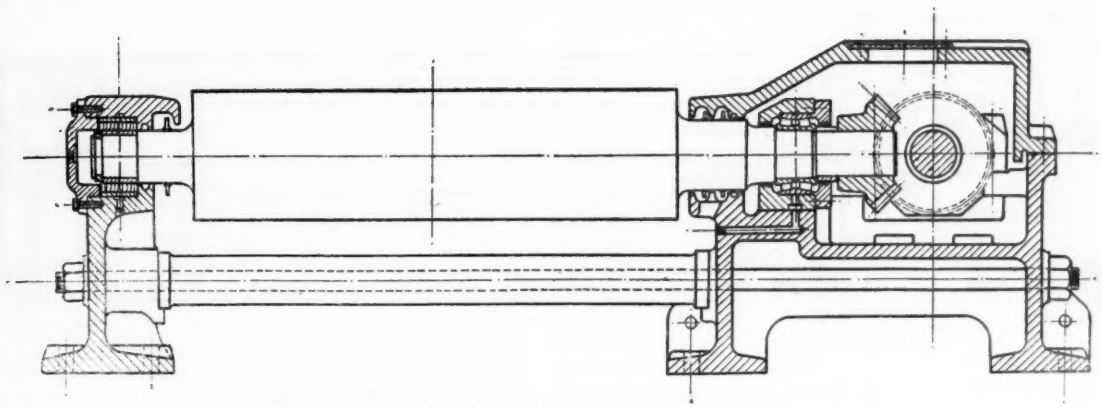


FIG. 1—Section through roller table with anti-friction bearings

balanced loading conditions. Provision must be made under the tables for the collection and disposal of scale by washing into a suitably placed drain sump, by side-removed scale buggies, or by chutes into the main mill-scale trough. The disposal of scale is an important necessity and it would be interesting to have some comments on this question.

*Alternative Bearing Designs*

Figure 1 illustrates a modern American design of blooming-mill main table with roller bearings. The first essentials are the selection of a bearing of ample capacity to withstand heavy shock loads and of such physical dimensions as to permit of it being accommodated in the space available and yet providing a substantial assembly with a projected area of the outer race large enough to ensure that it will not be hammered into the main frame casting.

In the illustration are shown a double-tapered bearing at the drive end, to take thrust from the bevel gear, and a cylindrical bearing at the opposite end, to allow for expansion. Adequate provisions are made to prevent the ingress of scale and water by the provision of shrouds or an extension of the gear cover at the drive side and on the bearing cap at the offside and by fitting throwers on the roller shaft inside the shrouds at both ends.

The drive-side roller bearing is mounted in a separate housing bolted to the main frame inside the gear box, and the whole is enclosed by the gear case. This construction has two main advantages: (*a*) By using a separate housing, damage to the main frame from hammering by the bearing outer race is obviated, and the complete bearing assembly is readily replaceable if this trouble occurs within the housing itself; and (*b*) the greater ease with which a roller can be removed. After removing the bolts holding the bearing housing to the main frame, the whole roller assembly can be moved towards the offside until the bevel gear teeth are out of mesh. As the collar at the offside bearing is slightly smaller than the outer diameter of the inner race, it permits this movement as well as looking after expansion.

The lineshaft bearings are of the cylindrical type and each section is provided with a double-taper roller thrust bearing. The latter is designed on rather similar lines to the drive-side roller bearings to facilitate lineshaft removal. After a filler plate in the specially designed lineshaft coupling has been removed and the locating pins of the thrust-bearing housing have been withdrawn, the whole shaft can be moved longitudinally until the bevel gears are out of mesh; the shaft can then be lifted out vertically.

For lubrication of the roller bearings it is usual to use a pressure-operated system designed to supply a known quantity of grease at predetermined periods of time. On the offside the bearing housing is provided with a seal and as the grease thins out because of rise in temperature some grease finds its way through the seal and serves to lubricate it. On the drive side any excess grease is permitted to work its way into the oil bath of the gear case and must be cleaned out periodically. The gearing is lubricated by an oil-circulating system similar to that which will be described for the plain bearing table.

Figure 2 illustrates the construction of a modern British blooming-mill table with pressure-oil-lubricated white-metal-lined bearings, in which every precaution is taken to combat the ingress of scale and water and prevent the escape of oil.

White-metal lining is applied to the bottom step only of the table roller bearings and to both top and bottom steps on the lineshaft bearings.

The rollers are provided with double oil throwers close to the bearings, and a single oil

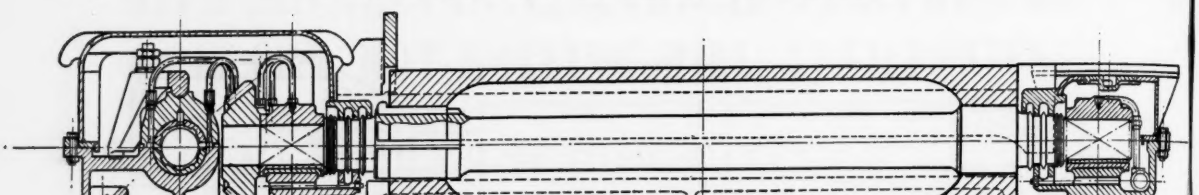


FIG. 2—Section through roller table with flood oil-lubricated bearings

thrower a little further away. Between these two sets of throwers is fitted a split-spring seal ring which is held in a machined spigot in the cap and frame. An additional thrower is provided to fling off external water and light scale, this thrower being outside the roller frame but enclosed on the top by an extension of the cap, suitably grooved to accommodate the thrower. The cap extension also forms an additional protection against scale.

The lineshaft bearings are located in front of the lineshaft mitre, that is in the cone of the mating pairs of mitres. The cap is held down by a single cramp which bears on the centre of the cap and is fastened by one heavy bolt. This arrangement permits the quick and easy removal of the bearing cap.

At the end of each section of lineshaft a combined thrust bearing and withdrawal gear is housed in the table frame. This unit takes the thrust from all the mitres and is fitted with a hand-operated worm gear which enables the complete shaft with its mitre and gear wheels to be moved longitudinally until the mitres are out of gear. This arrangement materially reduces the time and labour when it becomes necessary to remove a roller.

The lubrication of the bearings and gears is supplied from a central system which comprises duplicate circulating pumps, pressure vessel, settling and storage tanks equipped with heating and cooling coils, strainers, centrifuge, and pressure regulating valves.

A suitable alarm should be located in the operator's cabin to give warning of a clogged filter or a fall in oil pressure. It is not proposed to discuss the quality of oil as this has been fully dealt with in a recent paper by Mr. H. J. Knight.*

Oil is supplied by this system and is fed to each bearing by piping mounted inside the mitre troughs on the drive side and inside the oil trough and cover on the offside. On the drive side the oil after passing through the bearings flows into the mitre troughs where it is maintained at a suitable level to form the oil bath for the mitres. On the offside the lubricant flows from the bearing into a trough formed on the outside of the table frame. The oil is then piped back to the settling tank, cleansed, and recirculated. On a normal blooming-mill plant the circulating capacity for the roller table is in the neighbourhood of 120 gal./min., and the storage tank should hold between 20 and 30 min. pumping capacity.

As stated earlier these descriptions apply essentially to heavy mill tables. For runout tables, we believe everyone will agree that roller bearings are unquestionably the ideal bearings to employ, but it would be instructive to hear opinions or experiences on the bearing question for the heavy mill tables.

Electrical equipment forms a separate section of this paper but it might be mentioned here that for light runout tables individually driven rollers have definite advantages, such as simpler lubrication, less mechanical maintenance, and reduced shutdown time in the event of breakage or any failure. On heavy tables, however, lineshaft drive is preferable, because of the heavy and frequent reversals and the fact that for a large proportion of the operation only a few rollers are actually doing the work on short pieces, demanding large localized power, which is available from the high-powered single drive obtaining with the lineshaft construction.

### BREAST ROLLERS

It is interesting to follow the changes in design of breast rollers. The older arrangement is to drive them from the main tables through chains or gears with the rollers mounted in solid bearings. This design caused many breakdowns owing to the transmission of heavy shock loads from the mill delivery to the whole table. Breast rollers

* *Journal of the Iron and Steel Institute*, 1947, vol. 155, Mar., pp. 423–430.

in some cases have been freely mounted on the driven shaft, but this would appear to present some difficulty in entering short ingots to the mill.

They have also been driven from the mill pinion housing, with the roller bearings mounted on springs to ease the shock, but this has not been entirely successful and changes have been made to improve the operation.

The modern method is to mount a solid forged steel roller in a solid sleeve bearing carried in a bored hole in the roll housing. The bearing comprises a white-metal-lined sleeve carried in a steel cartridge. The inner bore of the cartridge has two independent sets of spiral grooves cut into it. Through one set is fed grease, which is led through suitably arranged holes in the sleeve to the bearing proper. Water is circulated through the second set of grooves to give an efficient cooling effect to the sleeve. The hole in the roll housing is bored on the taper, which facilitates the removal of the cartridge when required.

The breast-roller drive may also be arranged to drive the first feed roller, which is mounted in bearings carried on the roll housing.

The power is provided by an independent motor and is transmitted to the rollers through a reduction gear. The motor pinion engages with two gear wheels, each mounted on a quill which transmits the power to the gear shafts through a slipping clutch at the back of the gear box. Universal spindles complete the drive lines to the two rollers.

This arrangement has proved excellent in operation and simple in maintenance, although there is still some difference of opinion as to whether the slipping clutch is of any practical value.

A point of some controversy is whether the motor should be electrically connected to the main mill motor or to the main table motor. The latter method would appear to be preferable because the breast rollers follow the tables and the piece can be stopped on the tables immediately it leaves the mill, whereas with the former method the breast rollers follow the mill rolls and the piece is driven a considerable distance down the mill tables before it can be stopped, resulting in a slower return to the mill, which must have some effect on output.

Another method of driving the breast rollers, recently patented, which, although the same objection can be urged against it, is operating very successfully, is to take the drive from the bottom mill spindle, by gearing through a gear box and transmission similar to that described above. In this case, however, the complete reduction gear box is mounted on the bottom spindle balance gear so that it can follow any vertical movement of the spindle, which is compensated for by the universal elements between the gearing and the breast rollers.

### Universal Manipulators

Universal side-guard manipulators are called upon to perform a very exacting duty and must be designed to withstand heavy shock loads. In addition to moving the ingot from pass to pass and turning it up for edging, etc., they are frequently used to straighten a bloom.

The robust nature of the ingot manipulator for dealing with ingots varying in weight, say, between 5 and 20 tons is indicated by the fact that the total weight of manipulator mechanism can be 50–60 times the weight of ingot to be dealt with.

All-electric operation is the generally accepted practice both for the traversing of the heads and the operating of the tilting fingers but, as in other items, hydraulic operation has its adherents, either for all motions or for head traverse only with electric tilting gear.

Figure 3 shows a section through an electrically operated manipulator. The rack drives are all located on the drive side of the mill leaving the offside clear of any obstruction. This facilitates roll changing, scale disposal, etc., and while economizing in space assists maintenance by providing greater accessibility.

The heads are mounted on stalks forged

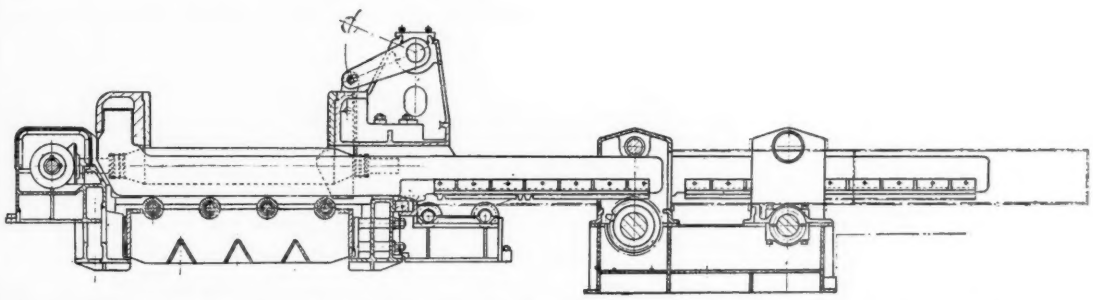


Fig. 3—Section through electrically driven ingot manipulator, showing operation of off-side head

integrally with the main operating beams, which are supported on and guided by rollers carried in roller bearings on the table-frame distance pieces and on extension members outside the tables. Separate machine-cut racks are bolted to the underside of the beams at the drive end, engaging with the driving pinions carried on the main longitudinal drive shaft. The driving pinions are housed in a totally enclosed box which also carries the top beam guide rollers, and the rack beams themselves are carefully enclosed to protect them from scale and dirt.

The heads are provided with renewable wearing faces and the section nearest the mill has a heavy extension member projecting practically to the mill rolls to ensure adequate guiding of the piece right up to the point of entry to the pass.

To resist the endwise thrust which may occur when a bloom is received from the mill, the heads are provided with a guide horn projecting downwards between two table rollers and running in a guide trough formed in a table tie girder.

The stroke of the manipulator heads is determined by the working length of the roll barrel and the speed of cross travel is usually in the neighbourhood of 130–140 ft./min. In order to give the utmost flexibility the motions are controlled on the Ward-Leonard system. The height of the heads depends on the duty of the mill and is, of course, made greater when the manipulator has to deal with slabs than when the product is blooms only.

In order to permit a table roller to be taken out, the drive-side head, which also carries the tilting gear, is provided with sufficient overstroke so that after removal of the back-working-stroke limiting stops and the extension guide member at the mill rolls, the head can be run back clear of the roller-table frames. The offside head, which normally does not carry any gear at all, can be lifted directly off the supporting horns by one lift of the crane.

### Tilting Fingers

Tilting fingers are freely mounted in a sliding block guided in pockets formed in the heads, and located longitudinally so that the two nearest the mill have close spacing for handling an ingot or short bloom and the remaining two fingers on wider pitching for turning the bloom as its length increases. The fingers are lifted and lowered by levers from a tilting shaft carried in bearings on the traversing head. In the past, motion has been given to this shaft through a motor-operated worm gear and cranks, all mounted on a trailing carriage attached to the manipulator head, involving trailing cables to the motor and demanding continuous maintenance to keep the mechanism operating satisfactorily.

The ideal arrangement is to have the motor and drive permanently bolted to the foundations; such an arrangement is shown in Fig. 4.

An operating-rack beam of similar design to, but of lighter construction than, the main head beams, is coupled to a lever on the tilting shaft, and supported in an enclosed combined guide and drive box.

The rack engages with a pinion which is driven through an idler by a pinion mounted on the main traverse-beam drive shaft. The tilting rack, therefore, positively follows the movement of the main side guards. The drive box carrying the tilting-rack pinion and idler is pivotally mounted on a trunnion on the idler-shaft axis. An oscillating motion is given to the drive box through a connecting rod, crank, and gearing from the separate tilting motor. When the tilting motor is operated the whole rack assembly is given a partial rotary motion around the trunnion shaft which results in a forward movement of the rack, operating the tilting shaft and fingers, so that tilting can be carried out when the heads are either stationary or in motion.

All bearings are of the roller type and lubrication of the gearing, etc., is effected from the central system.

### Hydraulically Operated Manipulators

It is claimed by the adherents to hydraulics that the man in the control pulpit can "feel" the operation, because of the resiliency of the system, and that the risk of damage by an over run is practically eliminated. In point of fact the speed of operation can readily equal that of electric operation provided that suitably designed valve

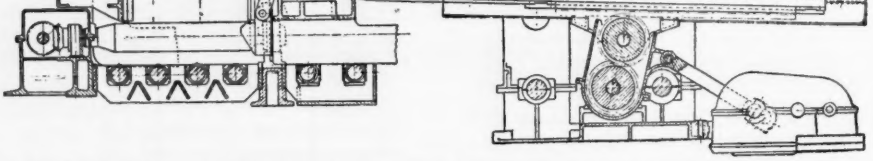


Fig. 4—Section through electrically driven ingot manipulator showing operation of tilting device

gear is supplied, and by incorporating small pilot operating valves and relay gear the operator's work is no more arduous than when he is using electric controls. Again it is argued that for a manipulator traverse a straight-line motion is required, which is directly provided by the hydraulic cylinder without the gearing necessary to convert the rotary motion of the motor.

Figure 5 shows a section through a manipulator which has all motions powered by hydraulic cylinders. The driving-rack beams, driving pinions, and main cross shaft are similar to those described for the electric manipulator, but the driving pinions and cross shaft receive their motion from a pair of outside-packed-ram cylinders, coupled through a sliding crosshead by links direct to one beam. The motion is transmitted to the other beams by the racks, pinions, and cross shaft.

As will be seen the main cylinder and inner ram are fixed and the intermediate ram cylinder is the movable element which operates the sliding crosshead. For the forward stroke pressure water is admitted through the inlet in the outer cylinder, causing the ram cylinder to travel forward, while for the return stroke water is admitted through the hollow fixed inner ram into the bore of the ram cylinder, giving the latter its backward motion. In actual practice the return stroke is always under constant pressure so that immediately the forward operating valve is open to exhaust the head returns to its outer or ambushed position.

The tilting fingers, which are also hydraulically actuated, are generally of similar design to the electrical manipulator. Power is provided by two vertical cylinders mounted on a fixed bedplate and operating a double lever with an extended boss which forms the journals of the supporting bearings. The bore of this boss is splined and running through it is a similarly splined shaft, the end of which is attached to the tilting head beam. Keyed close to the head end of this splined shaft is a lever, which in turn actuates another lever at right angles to it, the latter directly operating the tilting shaft. With this arrangement the splined shaft can travel longitudinally with the manipulator head and at the same time and in any position of the head be revolved and so operate the tilting gear.

The hydraulic manipulator just outlined has proved extremely successful in practice and its operation is as speedy as any electric manipulator.

### Screwdown Gears

A mill-screwdown gear is a very inefficient piece of machinery owing to its fundamental principle, and as no one has yet found an alternative method of applying controlled movement to the top roll of a mill, the engineers' aim has been to improve the overall efficiency of the whole unit as far as practicable. This has been done by introducing roller bearings throughout, totally enclosing all gearing, using the highest class of machine-cut gears, and by the scientific application of lubricants.

Screwing speeds are determined by the duty of the mill and vary from 36 in./min. on a plate mill to 300 in./min. on a high-lift slabbing mill. with a normal blooming mill in the neighbourhood of 200–240 in./min.

The usual practice is to employ two motors, one on each screw, mechanically coupled through a disengaging clutch coupling, so that while both screws are normally operated simultaneously they can be separated by the clutch for independent adjustment. Each motion should be of sufficient power to operate both screws in the event of a failure of one motor.

The motors have in the past been operated on the series-parallel system which gives a certain speed when screwing down and double that speed when screwing up. The tendency today, however, is towards greater flexibility of speed control and for this reason Ward-Leonard control is becoming the general practice.

The indication of screw setting on a big mill is usually done by means of a dial mounted on the roll stand. In order to give to the operator a fixed, and therefore error-constant, sight point, the finger or fingers should be fixed and the dial revolving. The dial is supported in a cover which

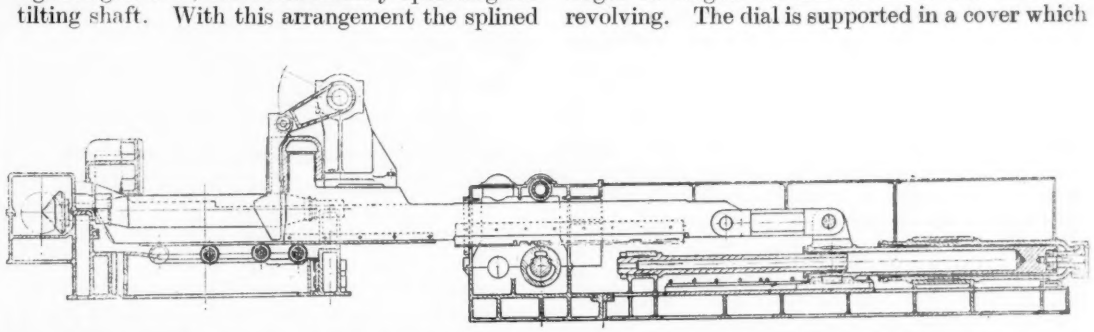


Fig. 5—Section through hydraulically driven ingot manipulator showing operating cylinders

has a window at the bottom showing only a portion of the dial; the finger is located within this window space and must be adjustable from the housing platform to compensate for roll wear. The window must at the minimum allow for the maximum reduction of roll diameter contemplated.

Screw setting may be indicated by a Selsyn transmitter and receiver. The transmitter receives its motion from some convenient point on the screwdown gear and transmits its rotation electrically to the receiver. The latter can be arranged to drive a dial of either the flat or drum type located in the operator's pulpit and calibrated to register the movement of the top roll. The main advantage claimed is the unimpaired view given to the operator, as against the possible clouding of the line of vision to the dial on the mill by steam, etc.

## Bloom Shears

The progress achieved in the development of the modern first-process mill could not have been successfully exploited without parallel developments in the apparatus for the effective disposal of the mill products in the precise form required by the rolling programme, and to this end much thought has been given to the design of equipment for shearing and removing blooms, slabs, and billets in the hot condition. The principal requirements of a shear and its auxiliary equipment are that it should be able to deal with the whole range of the mill products and to dispose of these at a rate at least equal to the maximum output of the mill.

To meet these requirements it is necessary for the shear to be sufficiently powerful to cut the maximum-size product, possibly at a limited cutting rate, and yet be capable of rapid operation when not required to work at maximum effort. For example, consider a shear operating in conjunction with a mill breaking down ingots into blooms for further rolling on a medium-section mill, which would be required to deal with a 10 in. × 10 in. bloom as a maximum duty. Here the principal purpose is to remove the front and back crop ends and possibly to divide each bloom once, for which a comparatively slow rate of cutting at maximum power is required. However, should the same mill be producing small blooms required for a merchant-bar mill, where the tonnage output would be considerably lower, a rapid succession of light cuts is called for, so that in a limited time it may permit the building up of a considerable stock of blooms. It is upon conditions such as these that the question of the selection of the type of shear most appropriate to any particular mill production schedule depends.

There are three categories of blade action which embrace all the shears normally used with first-process mills. They are:

(*a*) Down cutting.
(*b*) Up cutting.
(*c*) Down and up cutting.

### *The Downcutting Shear*

The principle of the down-cutting shear as illustrated in Fig. 6, is the simplest form of shear used for heavy bloom and slab cutting, but the advantages of simplicity are largely offset by the necessity of providing a depressing table to compensate the downward motion of the bloom as the cut is made. This type is most commonly used in cutting slabs for further rolling into plate or strip stock.

### *The Upcutting Shear*

In essence the upcutting shear is the above machine turned upside down and it dispenses with the need of a depressing table, as will be seen from Fig. 7. The disadvantages of a simple upcutting shear are that the full stroke has always to be made, with the result that when shearing shallow stock there is a considerable waste motion, and that the bloom must be raised into contact with the upper blade before cutting

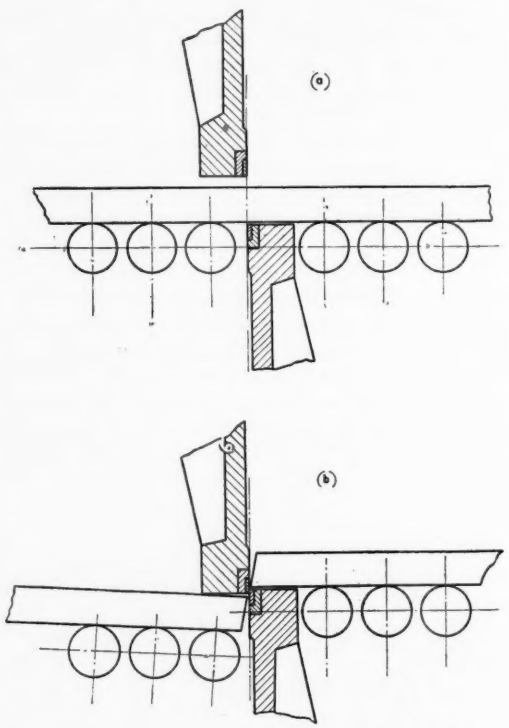



Fig. 6—Illustrating the action of the downcutting shear: (*a*) Bloom ready for shearing; (*b*) cutting stroke completed

begins. In consequence, especially when cutting shallow stock, the cut pieces must fall back heavily to the roller tables as severance takes place, unless a rising table is employed. Furthermore the bloom is at some time completely out of contact with the roller tables, which may result in violent turning movements as the blades take hold. To counteract these difficulties it has become customary to arrange for the position of the top blade to be adjustable vertically, so that the idle portion of the stroke is reduced to the minimum necessary to secure satisfactory clearance space when the blades are open. Quite a large number of bloom and slab shears of modern design have been built on this principle and are in successful operation.

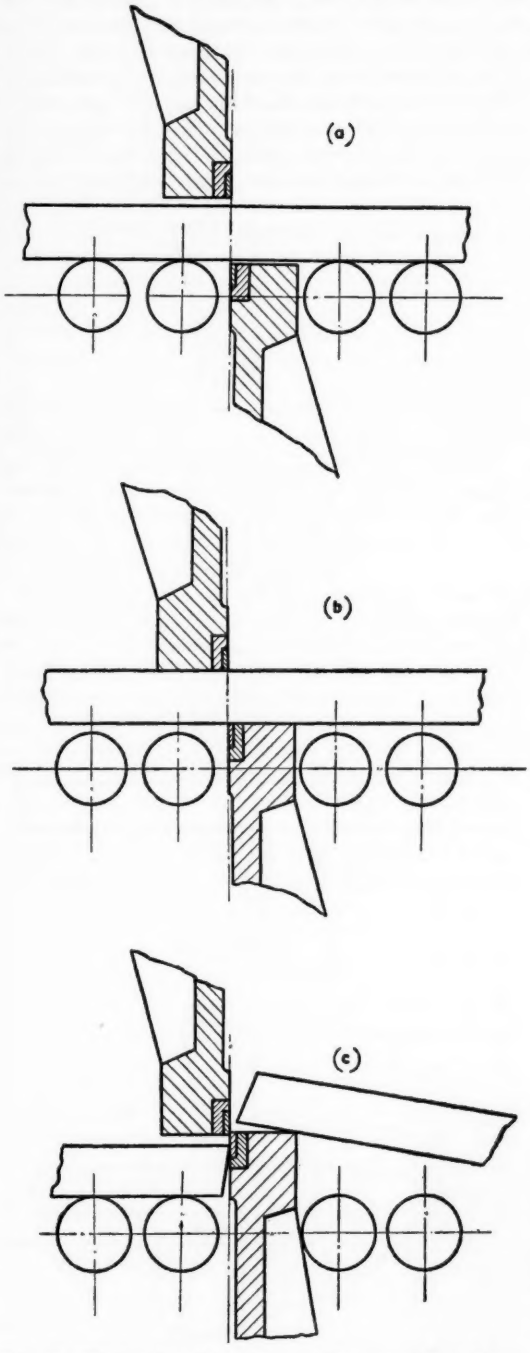



FIG. 7—Illustrating the action of the upcutting shear: (*a*) Bloom ready for shearing; (*b*) bottom blade ascends to clamp bloom on top biade; (*c*) bottom blade ascends to complete cut

### *The Down-and-Up Cutting Shear*

The down-and-up cutting shear has been developed to obviate the main disadvantages of each of the two types just described. By the consecutive movement of the two blades, in which the down stroke of the upper blade causes the bloom to be held firmly on the sill plate and the upper movement of the lower blade immediately following performs the cut in the upward direction, the bloom is held in control while the cut is made and the need for a depressing table is avoided. This type is in very successful use and some of these shears have been in service for a considerable period. The action of the blades is shown in Fig. 8.

### *Operation of Shears*

Heavy bloom and slab shears can be divided into two main classes, (*a*) hydraulically operated and (*b*), electrically operated.

In the range of shears from 10 in. × 10 in. capacity with a blade load of 600–700 tons up to the largest slab shears with a blade load around, say, 3500 tons, it may be stated that the upper limit for the economic use of direct electric driving is in the neighbourhood of 1200–1500 tons. Hydraulic power is used for shears above this capacity and can be economically employed down to, say, 600-tons blade load.

### *Hydraulically Operated Shears*

There are three types of hydraulic driving employed on heavy shears, the one hitherto regarded with the greatest favour being the steam hydraulic intensifier in which all conditions are exactly the same as in the well-known steam-hydraulic-intensifier forging press. The fineness of control which this system allows and its general all-round economy of operation make it very suitable for shearing, and when powered by steam from boilers utilizing the waste heat from soaking pits or steelmelting furnaces it becomes a very efficient and self-contained installation. The second type is the direct electro-hydraulic drive, which includes a high-pressure hydraulic

pump ; this system is also used economically in forging-press practice, although not as yet applied to shears. In this case the pump has to be designed with sufficient capacity and power to meet the heavy demand for comparatively short intermittent periods and is thus rather costly to instal. The drive for these pumps will require to be provided with flywheels or similar means of carrying the peak loads.

The recent development of the air-loaded hydraulic accumulator has introduced the indirect electro-hydraulic drive, which, although in its very early stages, promises to become superior to either of the other two. Owing to the absence of heavy ballast weights the air-loaded accumulator provides a shockless drive so that the relatively violent application and release of loading have no serious effects on the pipes and valves. Further, it provides for the use of a pump of a moderate size and power, the sole duty of which is to replace the fluid drawn from the accumulator. This can be done at a rate corresponding to the average demand, in this manner compensating for the heavy draws during the actual cutting strokes.

Owing to the necessity for keeping the sizes of rams and cylinder as small as possible it is not a practicable proposition to drive the hydraulic shear from the general hydraulic service main, which in most cases operates at a pressure of 1000 lb./sq. in. or less. In addition, the presence of hydraulically operated auxiliaries up and down the plant would cause fluctuations in pressure which would prevent the efficient operation of the shear. Neither would it be possible to drive the shear by means of a weight-loaded accumulator, as the surge in the pipe system due to the break-down of the resistance of the bloom as severance takes place and the sudden closing of the operating valve would set up very heavy peak pressures which would lead to frequent failures of pipe joints and glands.

The working pressure in a steam-hydraulic or a direct electro-hydraulic system would normally be 2½ tons/sq. in., with a possible 3 tons/sq. in. in the largest shears. For the indirect hydraulic system the maximum pressure would normally be 2 tons/sq. in., with a fluctuation of 5% either way to meet the operating conditions of the air-loaded accumulator, this being the maximum pressure at which this type of accumulator can be satisfactorily operated. The pressure in small shears may be as low as 3000 lb./sq. in.

*Electrically Driven Shears*

With one notable exception, in which a rack and pinion motion is used in conjunction with a reversing motor, electrically driven shears normally employ a crank movement for producing the reciprocatory motion of the blades. This means that the crankshaft must make one full revolution for each cut and if, as in bloom-shearing practice, it is not possible to arrange the production schedules so that cuts are made continuously the crankshaft must be started and stopped for each cut. In all small types of shear and the older types of large shear this may be done by means of a flywheel and clutch, but this has now given way to the start and stop motor. By this means the shock of the sudden start of the crankshaft is avoided, although, as the crankshaft has to be

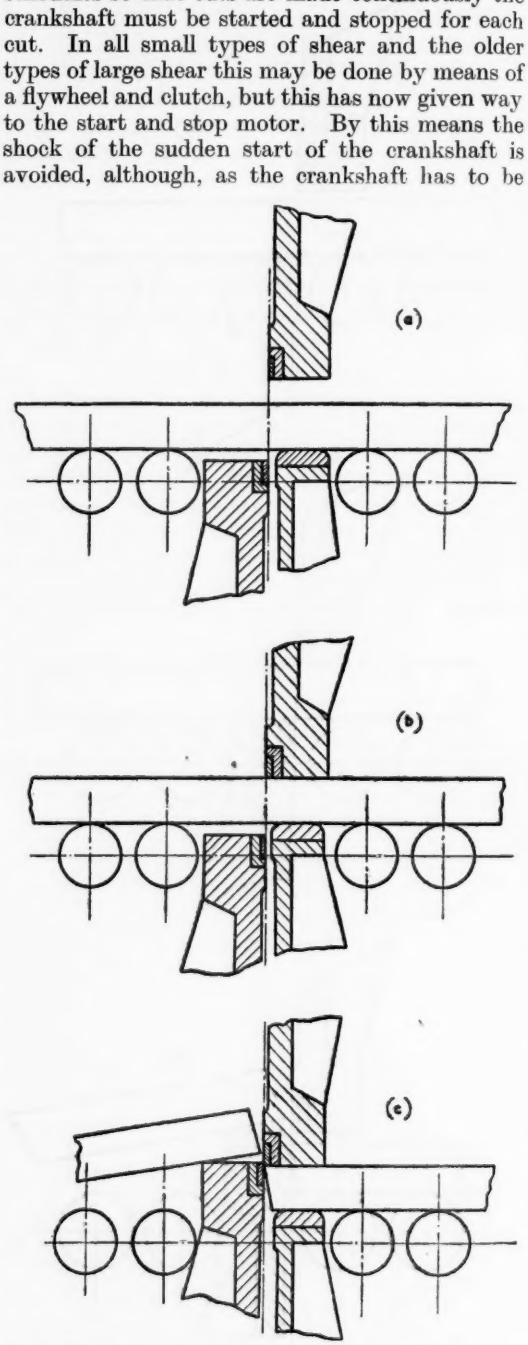



FIG. 8—Illustrating the action of the down- and up-cutting shear : (*a*) Bloom ready for shearing ; (*b*) top blade descends to clamp bloom on apron ; (*c*) bottom blade ascends to complete the cut

accelerated from rest to full speed in a small arc of its rotation, the starting effort required is very great. It has been found that a motor of the power required to provide this acceleration would contain an armature whose kinetic energy at full speed would be substantially sufficient to perform the heaviest cut without undue overload on the motor, so that it is only during the acceleration period that any appreciable overload has to be carried by the motor. The motor would have a speed range of about 4–1 so that it could be arranged to give up as much as 90% of the kinetic energy of the armature for the purpose of performing the cut, as compared with the 28% or so which is the maximum allowable with a flywheel.

Thus it is possible to use a comparatively low-powered motor capable of taking very high starting torque. To keep the size and weight of the motor as low as possible the current voltage is comparatively high, often necessitating a motor-generator set for the provision of the current.

From the constructional standpoint electrically driven bloom shears may be divided into two main classes, (*a*) closed or double standard and (*b*) open-sided or single standard.

The former class is more satisfactory from the construction standpoint, as the principal stresses in the main members are direct tension. The disadvantage of this type is the difficulty of getting crop ends and small cut pieces away from the shear. A disappearing roller or a pull-back table is required so that a gap may be formed in the roller table down which these pieces may be precipitated for removal by a skip or conveyor situated beneath the table. The provision always involves costly mechanical apparatus and foundation work, and to avoid much of this the open-side shear has been developed. In this type some or all of the main members are subject to heavy bending stresses, but it is not a difficult matter to design the parts to meet these conditions. As against this, the arrangements for removing the crop ends are extremely simple, consisting of one or two horizontal pushers arranged to push the crops off the roller table sideways into bins situated alongside the tables, from which position their removal is a matter of ordinary crane work.

### *Flame Cutting*

Before leaving the question of shearing it may be of interest to look towards the flame or gas-torch method of cutting and its relationship to steelworks cutting requirements. This method is in principle already well established in rolling-mill practice for the deseaming operation, and the exceptional conditions this process calls for have resulted in great advances in the design of gas-cutting torches.

Investigations are at present being carried out in this field but up to date there are no known developments. If it were proved possible with this method to equal the rate of cutting of a shear, the capital outlay and operative and maintenance costs should prove much lower than for a shear of equivalent capacity.

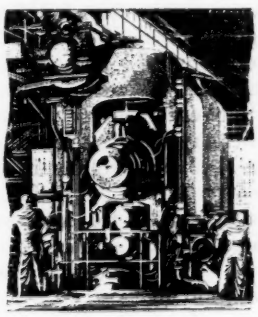
## Conclusion

In conclusion, it is hoped that the comparisons drawn between the different methods of construction and operation of the units discussed will be of sufficient general interest to promote a mutually useful discussion.

It will be noted that the important subject of lubrication has been little more than referred to in passing. It was felt that this had been so adequately dealt with by Mr. H. J. Knight in his recent paper "Lubrication in Iron and Steel Works Engineering" that to dwell on it here was superfluous.

## Acknowledgments

The author wishes to express his thanks to Mr. J. Meenan of the United Engineering and Foundry Company, Pittsburgh, for permission to use extracts from his recent paper, "Design of Mill Tables" (*Iron and Steel Engineer*, 1946, vol. 23, Aug., pp. 53–59).



## SECTION II—ELECTRICAL FEATURES

*By P. F. Grove, M.I.E.E.**

VERY little has been written about rolling-mill-auxiliary drives from the electrical point of view; lists of motors and occasional descriptions of new methods of operation are often to be found, but more attention is given usually to the broader aspect of mechanical equipment and the main-drive motor with its specialized apparatus and control.

Papers have been published on Ward-Leonard control as applied to some particular drives, such as mill screwdown, breast rolls, shears, and finishing auxiliaries, but there does not appear to be any comprehensive record of discussions on the electric drives and duties of primary mill auxiliaries as an individual group.

It is therefore attempted, in this section of the paper, to provide the basis for such a discussion, dealing with the application of electric drive to the machinery described in section I and such other problems as arise in choosing and arranging suitable electrical apparatus to serve those who operate and maintain the mill and its auxiliary equipment. Mention is also made of lighting which, although not an active part of the drives, plays a part in assisting the operators to maintain a high level of production.

### TIME AS A FACTOR

It is interesting to observe from the working of a reversing mill that, out of the total time for rolling an ingot, the sum of the periods required for handling by the auxiliary machinery is of the order of 50–60% for blooming and cogging mills and 60–70% in the case of slabbing mills. This fact demonstrates in a simple and forcible way that proper proportioning and control of the electrical drive exerts an important influence on the rate of output of the mill as a whole.

To roll one ingot takes a time of about 1 min. for the average number of rolling passes employed for this class of mill; the first passes take about 1½ sec. each and the time increases in regular steps to about 5 sec. as the piece rolled grows longer with successive reductions. For simple handling of ingots to enter the rolls on one side and to re-enter again on the other, the handling or what may be termed interval time is fairly constant at 1½–2 sec. A little longer may be taken for entry into different openings in the rolls and, for manipulating or turning the ingot, the time is increased to about 4 sec.

These interval times are an average applying to most reversing mills, based on practice for a maximum rate of production, but there are many possibilities of exceeding such short periods when operations do not go quite according to schedule. For instance, delay in setting the screwdown, failure of the rolls to bite, inaccurate alignment with the roll openings, straightening a bent piece, overshooting on the roller tables, and other faults of handling are heavy time wasters. As there are something like 2 million intervals between passes in an average working year of, say, 6000 hr., the accumulation of errors in interval time can seriously lower the number of ingots that can be rolled.

For actual rolling, the time is fairly closely controlled as a result of calculation based on tests and practice; and consequently a reasonably accurate schedule of events can be predicted. From this data the performance of the main-drive motor can be calculated with some precision and the control so arranged that, once a pass has been started, the working of the motor can be taken to some extent out of the hands of the operator. The main-drive control is centred on one lever and operation is carried out smoothly over the complete range of the rolling schedule, with a simplicity that is now taken almost for granted.

For handling, however, the interval time is determined more by the skill of the operator in judging the movements of the piece being rolled and is, moreover, dependent on the operation of several controllers, some actuated by separate operators.

It is, therefore, essential to provide the maximum accuracy and flexibility for each auxiliary drive to get the best out of the men's skill and judgment and to allow considerable margin for difficulties often outside their control.

There are cases where a measure of automatic working has been introduced by electrical means for working the handling auxiliaries to a set programme with the main rolls. This is becoming successful in its limited sphere, mainly for rolling non-ferrous material and steel plate, but for heavy ingots some further study and development is needed before it would be safe to leave the rolling in other than human hands.

It is felt, therefore, that the time is opportune for designers and operators to review the possibility of exploring further the actual duties of auxiliary drives in order to improve the design of

* Messrs. John Miles and Partners (London), Ltd.

electrical equipment with the object of increasing still further the efficiency of the mill.

## Range of the Problem

For consideration of the various problems that enter into the designs of electrical auxiliaries for a primary mill, the matter is divided under the following headings for convenience.

(1) Mill-type motors.
(2) Rating and duty of electric drives for :
  (*a*) Roller tables.
  (*b*) Breast rollers.
  (*c*) Manipulators.
  (*d*) Screwdown.
  (*e*) Heavy shears.
(3) Ward-Leonard control and choice of supply.
(4) Control-gear type and layout.
(5) Cabling and power distribution.
(6) Lighting.

### (1) *Mill-Type Motors*

It has long been established that only a motor specially designed for steelworks' conditions will meet the heavy service required. The name " mill type " is commonly known to all steelworks' engineers, but it may be as well to record the features that are indicated by this title.

Primarily the motor is totally enclosed to guard against dust, scale, and water spray. The frame and feet are of exceptionally sturdy design and made of steel. The frame is split horizontally for easy access to internal parts and to enable the rotating portions to be removed quickly. The shaft is specially strengthened to withstand severe shocks and is extended for driving at both ends. The bearings are liberally proportioned for heavy duty ; they may be of either the oil-lubricated sleeve or the roller type, although the latter are becoming more usual now, to take advantage of lower friction loss and reduced maintenance. Clearances are very ample throughout to meet the mechanical requirements of the drive and to allow margins for the dust, which breathes in and out of the machine because of changes in temperature. Conditions in this respect, however, can be improved by forced ventilation, which is dealt with later.

In addition to these better known features it is as well to stress that strength applies not only to mechanical parts but also to electrical parts such as windings.

To connect the motors electrically it has been usual to employ flexible cable tails, which are easy to handle for quick replacement of the whole unit, but of recent years there has been a tendency to tidy up the cabling by adopting fixed terminal boxes as on standard industrial motors. In this case the cables are protected from mechanical damage, but the box should be so arranged that it can still be quickly disconnected if the motor is removed and without damaging the cable. Cable boxes are sometimes placed on the top half of the frame but it would seem better to place them on the bottom half, or split with the frame, so that the more frequent operation of opening the top half of the motor will leave the cables undisturbed. When fixed steel tubing is used to enclose the cables it is advisable to provide some adjustment between it and the terminal box to allow for alteration in alignment of the motor with its drive.

A point worth noting is that, if full use is to be made of the double-ended shaft extension, there must be provision for a double set of cable and ventilating ducts. These will be on opposite sides of the machine and centred to suit the cable box and duct whichever way round on the motor it is placed.

To complete the mechanical features of the motor it is preferable to mount it separate from the gearing, driving through a flexible coupling, so as to provide independent alignment of the two units. This avoids back gearing on the motor frame, which is more liable to be damaged by shock. The coupling may also be used as a brake drum, which reduces the number of rotating parts, and thereby the moment of inertia of the drive, which is mentioned later.

The electrical characteristics will be dealt with under the heading of rating, but attention may be drawn here to the method of measuring temperature rise on motors of this kind. It is usual to specify a maximum temperature rise of 75° C. as measured by the thermometer. The rise is determined by placing the thermometer on accessible parts of the machine after it has stopped on test. It is suggested that it would be better to specify the method of measuring temperature rise by resistance, owing to the unreliable nature of any thermometer reading taken on the surface of windings. These are mainly short-time rated machines and, the shorter the rating, the more deceptive are surface readings.

The foregoing remarks apply to temperature guarantee, but for experimental purposes a useful reading of temperature rise by thermometer can be obtained under running conditions of D.C. machines, by inserting a thermocouple detecting element in a pocket in the compole windings. This gives a reasonably close check on armature temperature and can be read at a distance to find the effect of the duty on which the motor is engaged.

Finally it is worth drawing attention to the standardized frame sizes which have been arranged to conform with American standards. These apply to constant-voltage D.C. motors, but the makers might do well to standardize

also such speeds and ratings as are suited to variable-voltage working. There is much benefit to be obtained from a universal use of the standards from the point of view of parts for quick replacement and reduced costs.

(2) *Rating and Duty of Electric Drives*

Selection of the size of auxiliary motors has, up till now, been largely on a basis of short-time rating, of which the only definition to be found in British Standard Specifications is the output at which a machine can work for a specified time, such as one hour or half an hour, without exceeding a given temperature rise. How soon another period of loading can be applied is obscure and, as a basis for rolling-mill duty, the intermittent rating seems of little value.

The equivalent continuous-heating rating or R.M.S. rating of a motor working on an intermittent-duty cycle can be calculated quite easily either graphically or by simple mathematics. For example, the R.M.S. rating for a cycle requiring, say, 50 h.p. for 10 sec. followed by 100 h.p. for 5 sec. and 0 h.p. for 30 sec. is worked out as follows :

$$\text{H.p. (R.M.S.)} = \sqrt{\frac{(50^2 \times 10) + (100^2 \times 5) + (0^2 \times 30)}{10 + 5 + 30}}$$

$$= 41 \text{ h.p. equivalent continuous-heating rating.}$$

This, however, is not all, because it is necessary to take into account two other factors, namely, the maximum overload torque and the rate of acceleration.

The maximum overload torque can only be assessed by tests on the drive but the rate of acceleration can be calculated from the moment of inertia or $WR^2$ of the motor and drive.

There is not space here to give a worked-out example for this, but reference can be made to a useful article on the subject by Umansky,* as long ago as 1922, in which the need for studying the relation between inertia forces and motor rating is very well reviewed.

Coupled with this, a good deal of information is available on the main drive as a result of tests made by Puppe and others, together with time studies such as those published by the Iron and Steel Institute in 1938.†

It is therefore urged that more tests should be made on individual auxiliary drives to determine some precise ratings based on the general cycle of work to which the mill works as a whole.

Auxiliary drives provide a large variety of rating conditions ranging from running light to stalling, interspersed with frequent reversing at a high rate of acceleration and braking, so a brief review may be given of the general characteristics of each drive as follows :

(a) *Roller Tables*

The motor may be in operation up to 90% of its time and although the R.M.S. rating can show something approaching a continuous duty, there are periods of light-load running, heavy peaks and reversal, which determine a basis other than heating for the design of the motor.

Individual or group drive has been commented on in the mechanical section. From the electrical point of view also there is much in favour of group drive. The need for rating the motor to meet the conditions of one or two rolls taking most of the load, means that with individual drive the tables will of necessity be much over-powered. At the same time the restriction in size to the diameter of the rollers and the awkward position under manipulator machinery, make individual main-roller motors difficult to design for reliable operation. Such motors have been flange-mounted and designed for A.C. working, which from experience have caused trouble. The main reason for this is probably that the torque is dependent on the square of the voltage and reductions in voltage are accompanied by severe reductions in torque, just at the moment when the drive requires all it can get. If the voltage is maintained high enough to meet this, then the motors become too hot. Variable frequency does not improve matters, again because of the difficulty of one or two machines taking all the load.

With group drive, however, the motors can be of the standard mill type, are easily accessible, and their rating predicted with more accuracy.

Smooth variable-speed drive is of advantage with rollers and could probably do much to overcome the trouble of shock when receiving an ingot at speed from the main rolls. The practice of running the rollers inwards to the mill to avoid overshooting is detrimental on account of the heavy shock and could probably be avoided by running the rollers with the mill, but at a lower speed, under full control. Such can be achieved by Ward-Leonard D.C. control, which covers all the wide range of operation already mentioned.

(b) *Breast Rollers*

There have been troubles on the mechanical side and electric drive is becoming favoured now. It seems logical to employ an independent electric drive, which can be varied to suit the speed of either the main rolls or the roller tables. For this reason the present American practice of providing a separate Ward-Leonard generator for each of the breast rolls, seems better than that of connecting the motors either to the main roll-motor circuit or to that of the table rollers. The

* L. A. Umansky, *General Electrical Review (America)*, 1922, vol. 25, Oct.–Nov.

† *Iron and Steel Institute*, 1938, *Special Report No. 20*.

cost is naturally higher, but the proper functioning of breast rollers can do much to lighten the duty on roller tables and save time by ensuring immediate bite of the piece, which is one of the points stressed at the beginning of this section.

The use of a separate Ward-Leonard drive makes it possible to feed the ingot into the main rolls at the proper speed for entry and to take the ingot out of the rolls at the same speed as the outgoing roller tables, so that it is probable that the controversy as to whether the breast rollers should run with or against the mill on the delivery side can be resolved.

(c) *Manipulators*

Rapid acceleration and deceleration is needed here, combined with accurate braking. High continuous speed is not needed and may even be dangerous. Acceleration must also not be too fierce, otherwise there will be continual overrunning, which wastes time.

Occasionally a longer piece is straightened between the manipulators and considerable power will be needed under stalling conditions. The exact amount of power can only be determined by tests.

Here is a case again for Ward-Leonard control, especially for its feature of regenerative braking. The time for operation of mechanical brakes is very short and the operation is so sudden that frequently much "inching" is observed. The smoother braking by Ward-Leonard control in advance of the ultimate stop by the mechanical brake is of advantage here.

The tilting fingers working with the manipulators need a straightforward high-torque drive, but acceleration must not be too fast or fingers will be broken.

In both these cases, where acceleration must be fast and long running is not of importance, low-inertia motors are essential.

(d) *Screwdown*

The majority of movements on the main rolls are about 2 in. or less, with occasional movements of 3–4 in. This drive for the screwdown demands smooth and fast acceleration, with accurate braking. Some engineers call for heavy power for screwing down on an ingot or even for screwing up to release a cobble. Such events have occurred but it is considered less necessary now to cover these duties. In the case of screwing down it is almost impossible to provide enough power to produce a result which is really effective. For releasing a cobble, which is fortunately rare, mechanical means can be provided and are probably more satisfactory.

To meet the conditions low inertia is necessary, together with low gear ratio. Often now there are two motors, one on each screw, and these may be made each for full power to duplicate the drive. Forced ventilation is usually applied to keep down the motor size and inertia and is a distinct advantage in any case for the screwdown drive, because of the unsatisfactory position in the path of rising heat and steam. Ventilation is most necessary when the motor is still and no cooling is available from the running of its armature, so that forced ventilation becomes very desirable. Good use is made in America of the forced-ventilation ducts to carry the cables, which can also be kept cool and tidy at the same time.

Ward-Leonard control is now established for screwdown drive and meets the range of duty required.

(e) *Heavy Shears*

When electric drive is used for heavy shears it is becoming more usual to employ a start-and-stop drive for each cut. To estimate the duty it is necessary to work out separate cycles of operation, on the basis of torque and time, for the heaviest slow cut and the heaviest quick cut respectively.

As already mentioned in the mechanical section, Ward-Leonard drive with a separate motor-generator set provides a convenient and economical means of control for this heavy drive, which is constantly starting and stopping. Moreover it is possible to provide very fast acceleration as and when required, with means for adjusting the value to suit operating conditions.

(3) *Ward-Leonard Control and Choice of Supply*

It will be seen that Ward-Leonard control has been recommended for all the heavy drives. Its advantages of adaptability to almost any duty cycle, smooth and exact speed control, inherent regenerative braking, and economy in operating cost, are already acknowledged. This is shown by its increased use, especially on new larger mills, at first for screwdown, then for roller tables and manipulators, and finally for breast rolls.

First cost is higher than for magnetic-contactor control, at constant voltage, but when making comparisons it should be remembered that savings in maintenance apply to mechanical as well as to electrical machinery, owing to the smooth controlled action causing less wear and tear.

Several methods are employed for variable-voltage control, but they can be roughly divided into two main categories—those which employ quick-acting exciters, such as the well-known amplidyne, metadyne, rototrol, magnavolt and cascade exciters, and the so-called "shovel" control first used on excavators, employing what is known as the three-field system. The former are the more expensive, because they employ both primary generators and secondary exciters, but



XUM

they deal with a very large range of characteristics, while using the smallest operating currents. Selection between the types, however, is largely dependent on examination of the duty cycles for each particular drive.

The increased use of variable-voltage meets half way the old problem of A.C. *versus* D.C. for heavy auxiliary drives and simplifies the arrangements for power supply. Groups of generators may be provided with driving motors large enough to employ high voltage, thereby avoiding concentration of heavy low-voltage supply as is the case with A.C. auxiliaries. The motor may also be designed for unity or leading power factor, as the local system requires.

There was a strong influence in Europe before the 1939–1945 war to use A.C. motors for all purposes on the pretext of saving conversion losses. This was especially the case in Germany, but the true reason was probably to reduce first cost. Losses in conversion can soon be offset by the increased size of A.C. motors needed to meet the conditions already referred to, and the heavy low-voltage distribution switchgear needed for A.C. working.

Independent variable-voltage control for this group of auxiliaries is moreover superior also to bulk conversion to D.C. constant-voltage supply, because there is no interference from variations on the supply system outside. It is not intended therefore here to review any of the arguments involved in comparing A.C. and D.C. motors under constant-voltage control, because of the tendency now to adopt Ward-Leonard working.

### (4) *Control-Gear Type and Layout*

The use of Ward-Leonard drive has a pronounced effect on the control equipment needed, because of the large reduction in the number of contactors, compared with constant-voltage operation. The problem of housing large banks of contactor panels near the mill is simplified and all the apparatus needed for motor generators and exciters can be accommodated in the main motor room. In this connection some attention might be given to reducing as much as possible the number of contactors used in Ward-Leonard working.

The use of small master controllers in the pulpit has introduced a number of contactors, but there seems no reason why there cannot be a reversion to the use of face-plate controllers to a greater extent. The chief reasons for abandoning face-plate controllers on the main roll drive were the space taken up and the mechanism needed to reduce the size of the operating handle for hand control rather than arm control. With the recent improvements, however, in mechanical remote-control systems, it should be possible to mount regulators in convenient positions on the pulpit and still retain the small handles. With quick-acting exciter control it may be possible to house the small-sized controllers in the operator's desk, with direct lever operation as in the case of continuous multi-stand mills. Discussion on this suggestion might be useful.

By paying some attention to the construction and layout of the operating pulpits, good conditions can be arranged for both the electrical equipment and the operators. The bulk of the apparatus being housed in the motor room, all the electrical equipment could be placed in clean, well-lighted, and ventilated positions, which leads to easier maintenance and improved safety. This is already the general practice in hot-strip-rolling mills and can as easily be applied to individual reversing mills.

Whether electrical equipment should be mounted on open or enclosed panels may be a matter of preference or habit, but for proper isolation and safety, only total enclosure can be recommended in any situation.

While making this recommendation the author realizes the claims for open panels in a motor room or substation. It is difficult to see the contactors when enclosed, and glass fronts present difficulties. A concession may be made by stipulating that A.C. switchgear for starting motor generators, pumps, and fans shall be totally enclosed, while D.C. equipment can be mounted on open panels if proper precautions for safety are observed. This will apply to the general line of Ward-Leonard control.

Pulpit layout requires a co-ordinated system for the ease and comfort of operators, with the controls placed as handily and compactly as possible. It is suggested that a combined desk is possible, incorporating main roll drive control in the centre, with the auxiliary controller handles grouped round in partly circular formation. A wide angle of vision of the mill is desirable and for this purpose the front window could be bay-shaped. Vision is also needed at the back and can be obtained by the use of swivelling seats and similar bay-shaped windows. Some controls may even be overhead, such as those for infrequent operation. The on-and-off approach and run-out table controllers could be treated in this way. Foot controls are possible and sometimes used, but there is the possibility of inadvertent operation which might cause trouble ; in the author's opinion they are more tiring to use.

With combined control desks it may be advisable to mount the levers on a temporary bench for initial starting up, because the final best position of operators is very difficult to arrange in the design office. Nearly always alterations are required before the operators settle down.

*Brakes*

A remaining item of control gear is brakes. The most reliable for heavy duty are D.C. and, where Ward-Leonard control is used, auxiliary generators can be provided on the motor-generator sets for giving constant-voltage auxiliary supply for this purpose. The author considers this better than using another possible external D.C. supply which may be available for cranes or other mills, because the primary mill auxiliary system should be self-contained and independent, so that there is no trouble from interference.

It is not intended here to describe any details of brakes, but to say that they should be designed for quick dismantling for replacement of linings and removal of the drum.

A further point which affects all control gear having hinged moving parts is that hinge pins need to be of rustless steel. This applies to contactors, controller handles, relay parts, brakes, and all other equipment.

(5) *Cabling and Power Distribution*

The conditions for cabling round the mill are not good, owing to the heat, scale, water, and oil present; there is, moreover, very little room for adequate cable tunnels or trenches. For this reason it is advisable to provide all cables with mechanical protection, either lead-covered and armoured, or by heavy steel tubing. Armoured cable is preferred mainly in British mills and is the most durable form but it should be run in adequate ducts and supported on racks or trays, away from accummulated water and oil. Steel tubing has been adopted more in America, using plain tough rubber insulating cable. It is sometimes considered in this country that the cable would be better with a braided covering on the rubber to give added protection against damage. The tubing in any case must be free from roughness inside and should be specified as rodded and reamed.

Of the two methods the author is inclined towards rubber–cambric–asbestos insulated cable with lead covering and armouring as being the most durable for the conditions of a primary mill. Two tunnels as large as possible can be built under the mill, one near each main pulpit, in which the cables are best racked down the sides with room for a man to stand. From the tunnels the circuits to pulpits should run in protective steel ducting and those to motors in trenches alongside the machine foundations, as far as possible. In any case cables should be supported firmly throughout this run and not left loose anywhere. Circuits running along the mill machinery, such as those to the screwdown, are best protected and tidily run in steel ducting, which can be combined with the ventilation system as already mentioned.

The use of armoured cable calls for cable boxes on the motors (this was dealt with under the heading of Mill-Type Motors).

A most important part of the system is the earthing. The author considers that the earthed frame of every motor and piece of electrical apparatus should be bonded with substantial connections to a solid copper earth-bar system running round the mill and joined to the rest of the earthing system in the motor room. This includes all motors, control gear, brakes, limit switches, and pulpit equipment. The earth system should be visible wherever possible for maintenance. To rely on the armoured sheaths of cables and their armour clamps on cable boxes or on steel tubing is not good enough for continuously bonded earthing and these parts themselves should be bonded independently to the main earthing system.

For power-distribution control there are schools of thought as to the relative merits of oil-break and air-break switchgear. Where the supply switchgear is located in the mill-motor room the author has a preference for air-break, but to enter into a discussion on the subject here would be outside the scope of the paper. It is, however, desirable that all the distribution switchgear should be of the enclosed-cubicle type for safety and protection against dust or oil vapour, which cannot entirely be avoided even in well-ventilated motor-room substations.

When Ward-Leonard control is employed throughout for the mill auxiliaries it has already been said that the generators can be grouped so as to employ fair-sized driving motors which can be connected to a medium-high-voltage A.C. supply. This avoids heavy concentrations of low-tension power, which in the case of A.C. are very undesirable. Even in the case of D.C. constant-voltage systems it is better to avoid a multiplicity of heavy circuit breakers which all require maintenance.

The arrangement and layout of distribution equipment is more a matter concerned with the mill as a whole and includes the main motor equipment, so it will not be dealt with here. Adequate ventilated basement tunnels to receive the mill cable tunnels are, however, a feature requiring close attention for both main and auxiliary equipment.

(6) *Lighting*

A good deal could be done in this country to improve the standard of lighting in heavy mills. There is no need to think that because the conditions are bad any sort of lighting will do. The practice often adopted of running P.B.J. bus wires in the roof is not, in the opinion of the author, a really durable and safe kind of instal-

lation. It has been said that P.B.J. wiring on insulators will stand up more to corrosive fumes, and even if the covering wears away the wires are still insulated, whereas conduit installations corrode badly at screw-threaded joints, and defects in wiring are not so accessible. This is arguable, but a really good galvanized conduit installation will last a long time. A good method, which is sometimes discounted because of cost, is the use of paper-insulated lead-covered and armoured cable, wiped and terminated in armour clamps at ample-sized pull-in boxes for each fitting ; this is almost indestructible.

Fittings should be of high-mounting intensive-reflector type and, in the author's opinion, fitted with visors. A certain amount of dirt gets drawn in because of the heating and cooling, but the glass visor certainly does prevent damage to the reflector surface, which is the worst trouble in a steelworks.

Regular maintenance of lighting fittings is essential and there is no way of avoiding continual attention, but with cranes available this is not unduly difficult. A help to maintenance is to have every fitting detachable by means of a hook and plug connection so that it can be removed for cleaning more easily and sometimes completely replaced with a spare unit. A combined plug and hook arranged so that the plug has to be taken out before the fitting can be removed is useful and tends to electrical safety.

Whether tungsten, mercury, or fluorescent lighting should be used is open to debate. Tungsten is probably more suited to hot-metal working, but mercury is economical and more penetrating. The author is a believer in mixed mercury and tungsten, because of the quality of light and the standby effect of tungsten if mercury fails owing to a momentary cessation of supply or excessive voltage drop. Fluorescent lighting is still expensive and more maintenance is required, but the eventual trend will probably be towards this kind of illumination for all industrial purposes on account of its quality.

It is proposed here to make a bold plea for better use of lighting by painting the interior of buildings in a light colour. Such a proposal sometimes meets with objection on the score of extravagance, but a building has to be painted in any case, so why not start with it light ? From experience with foundries treated in this way, it is surprising how long the appearance of lightness lasts, and before its effect is appreciably lost the metal work will require repainting to prevent corrosion. Light colours are beneficial to all motor rooms, control houses, pulpits, and other enclosures for electrical equipment and provide an inducement to preserve a good level of maintenance.

As to lighting distribution, the use of re-wirable porcelain-handle fuses is not good and either high-rupturing-capacity fuses or miniature circuit breakers should be used. The latter are convenient and require no maintenance—before the war several large installations employed miniature circuit breakers imported from America and these cost very little more than conventional fuseboards, but manufacturers in this country are behindhand in this respect.

Finally it is advisable to derive lighting supply from a source separated from local power circuits. The voltage for lighting suffers too often from power-switching currents and it is safer to ensure the lighting supply irrespective of power distribution. The practice of employing separate lighting transformers connected to the high-voltage distribution system is to be commended, because it reduces the short-circuit current on the lighting system. Many dangerous accidents in changing lamps and other minor unskilled operations could be avoided in this way.

There should be a regular system of plug points installed around the plant for maintenance. These should be protected by earth-leakage equipment, owing to the dangerous nature of trailing flexes and portable electrical equipment when working among earthed metal structures—often in awkward positions. This may sound trivial in a paper dealing with heavy mill auxiliaries, but safety is a duty besides being important to production. Safe equipment is available and heavy plants should set an example to smaller industries in this respect.

## Conclusion

The main aim of the foregoing review of electrical matters affecting auxiliary drives is to improve production and lower operating costs by promoting more detailed study of every individual drive. Some of the practice described or suggested may seem expensive, but capital costs will be recovered by eliminating waste of time and delays caused by accidents to both machinery and personnel. The outline is drawn on a broad basis for initial discussion, but it is hoped that co-operation between designer and operator will result in closer studies being made on a quantitative basis to find out more about the characteristics of the drives in question.

## Acknowledgment

The author wishes to express his thanks and appreciation for encouragement and suggestions from several quarters.

# NEWS

ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

## THE IRON AND STEEL INSTITUTE

### Autumn Meeting, 1947

Further details can now be given of the programme for the Autumn Meeting of the Institute, which will be held on Wednesday and Thursday, 12th and 13th November, 1947.

Official business, including the election of Members and Associates, will be conducted at 10.0 A.M. on Wednesday, 12th November. The papers for verbal discussion will be presented as follows :

**Wednesday, 12th November, 1947**

**10.0 a.m. to 1.0 p.m.—Morning Session**

10.15 A.M. to 11.45 A.M.—(i) Joint discussion on :
"*Hydrogen and Transformation Characteristics in Steel*," by J. H. Andrew, H. Lee, H. K. Lloyd and N. Stephenson (*June*)*
"*Hydrogen in Steel Manufacture*," by C. Sykes, F.R.S., H. H. Burton, and C. C. Gegg (*June*)

11.45 A.M. to 1.0 P.M.—(ii) Joint discussion on :
"*Brittle Fracture in Mild-Steel Plates*," by W. Barr and Constance F. Tipper (*October*)
"*The Effect of the Manganese/Carbon Ratio on the Brittle Fracture of Mild Steel*," by W. Barr and A. J. K. Honeyman (*October*)
"*Some Factors Affecting the Notched-Bar Impact Properties of Mild Steel*," by W. Barr and A. J. K. Honeyman (*October*)

**2.30 p.m. to 5.0 p.m.—Afternoon Session**

2.30 P.M. to 4.15 P.M.—(iii) Joint discussion on :
"*A Note on Variations in Producer-Gas Quality*," by J. E. de Graaf (*October*)
"*The Distribution of Fuel in Gas Producers*," by M. L. Hughes (*May*)
"*Experiments on Gas Flow in Producer Fuel Beds*," by M. L. Hughes (*July*)

4.15 P.M. to 5.0 P.M.—(iv) Discussion on :
"*A Photo-Electric Roof Pyrometer for Open-Hearth Furnaces*," by T. Land (*April*)

**Thursday, 13th November, 1947**

**10.0 a.m. to 12.45 p.m.—Morning Session**

10.0 A.M. to 10.45 A.M.—(v) Discussion on :
"*The Fluidity of Steel*," by R. Jackson, D. Knowles, T. H. Middleham and R. J. Sarjant (*September*)

10.45 A.M. to 11.45 A.M.—(vi) Discussion on :
"*The Mechanism of Carbon Removal by Oxidation from the Bath in the Open-Hearth Furnace*," by the late A. H. Jay. To be presented by G. E. Speight (*October*)

11.45 A.M. to 12.45 P.M.—(vii) Discussion on :
"*Some Aspects of the Refining of High-Phosphorus Iron*," by W. L. Kerlie (*October*)

The Sessions for both days will take place at the offices of the Institute, 4, Grosvenor Gardens, London, S.W.1, and not at the Institution of Civil Engineers, as previously advertised.

A Buffet Luncheon will be held in the Library of the Institute on Wednesday, 12th November.

* The issue of the *Journal* in which the paper appears is given in brackets.

### Joint Meeting in Sheffield

At the kind invitation of the Sheffield Metallurgical Association a Joint Meeting of that Society and the Iron and Steel Institute will be held at the Sheffield Metallurgical Club, 198, West Street, Sheffield, 1, on Tuesday, 4th November, 1947, at 7.0 P.M. Mr. T. F. Russell, F.I.M., President of the Sheffield Metallurgical Association, will preside.

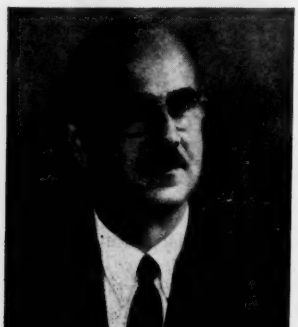
Two papers, one by Dr. C. Sykes, F.R.S., Mr. H. H. Burton and Mr. C. C. Gegg on "*Hydrogen in Steel Manufacture*," and the other by Professor J. H. Andrew, Dr. H. Lee, Mr. H. K. Lloyd and Mr. N. Stephenson on "*Hydrogen and Transformation Characteristics in Steel*," will be presented. These papers were published in the June, 1947, issue of the *Journal* (pages 155–180, and 208–253).

### Joint Library

In connection with the Autumn Meeting of the Iron and Steel Institute, and also the meeting of the Iron and Steel Engineers Group, the Reference Library will be closed on Wednesday, 12th November, and on Wednesday, 26th November, 1947.

## Staff Biography No. 10

Dr. M. A. VERNON, Information Officer, was born in London in 1906. He was educated at the Holborn Estate Grammar School, London, and at Trinity College, Cambridge, where he was elected a Senior Scholar and graduated in Natural Sciences.



He carried out research work on optical isomerism at the Laboratory of Physical Chemistry, Cambridge, and subsequently on high-pressure gas reactions, under the late Professor W. A. Bone, F.R.S., at the Department of Chemical Technology, Imperial College of Science and Technology. The results of his researches were published in the *Proceedings of the Royal Society* and in the *Transactions of the Faraday Society*, and he was awarded his Ph.D. degree for this work.

In 1930 he joined the Technical Department of the British Iron and Steel Federation and became Secretary of the Blast-Furnace Committee and its Sub-Committees. In this capacity he drafted the First Report of the Blast-Furnace-Practice Sub-Committee, published by the Iron and Steel Institute as Special Report No. 6. He also undertook the statistical analysis of blast-furnace operating data, and was joint author with E. C. Evans and L. Reeve of "*Blast-Furnace Data and their Correlation—Part II*," which was presented to the Iron and Steel Institute in 1931.

In 1936 he went to the Department of Technology of the City and Guilds of London Institute in an administrative capacity, and among his other duties he was Secretary of the Advisory Committee on Metallurgy. He assisted in the revision of the scheme of metallurgical examinations in 1938 and again in 1946, when they were brought in line with the newly established National Certificates in Metallurgy.

He was commissioned in the R.A.F.V.R. in 1940 and in 1944-45 he served as a staff officer in the R.A.F. Delegation to the Combined Chiefs of Staff, Washington, D.C., with the rank of squadron-leader.

After his release from the R.A.F.V.R. in December, 1945, he returned to his old post for a brief period, and on the reorganization of the Information Department of the Iron and Steel Institute he was appointed Information Officer in June, 1946.

## The Information Department

One of the most important functions of the Institute's Library has always been the provision of an information service, mainly technical, to its Members; and the popularity and success of this service has been shown in the past by the considerable and increasing number of enquiries that have been received from Members, Industrial Companies, and Government Departments, both in this country and abroad. In the years immediately before World War II the work involved in meeting these demands was assuming such dimensions that it was becoming clear that some expansion and reorganizing would be necessary to maintain an efficient service. Any expansion was naturally precluded during the war, but immediately afterwards the problem became urgent as a result of the formation of the British Iron and Steel Research Association. It was therefore decided, in 1946, to appoint an Information Officer to reorganize the Information Department under the general direction of the Librarian. The first task of the Information Department was to begin the compilation of a classified technical index to the world's literature on metallurgy and kindred subjects to enable all enquiries to be dealt with accurately and promptly.

The compilation of this classified index must inevitably take time, and priority has been given to this task. The main sources of such information on ferrous metallurgy are the abstracts published monthly in the *Journal of the Iron and Steel Institute*, and it is aimed to make these abstracts as nearly complete as is practicable. To this end the whole question of technical and trade periodicals taken by the Library has recently been the subject of detailed consideration by the Joint Library Advisory Committee, and as a result of its recommendations the number and scope of these periodicals have been considerably widened. It is hoped that the abstracts will be still further increased in usefulness in the future as a result of the close connection which now exists between the Abstracting and Information Departments.

In addition, it is the intention, when time permits, to extend and amplify the records covering connected fields. Other notices will be issued when these arrangements have been completed.

The organization likely to make the most individual demands on the Information Service is naturally the British Iron and Steel Research Association, and the advantages of the closest possible co-operation between the Institute and the Research Association are manifest. Arrangements for ensuring this have been agreed and were set out in detail in the May, 1947 issue of the *Journal* (page 122). Queries which can be answered on the basis of existing published information are dealt with by the Institute, and

any enquiry which requires an expert metallurgical opinion and not merely a knowledge of published information is answered by the appropriate technical officer of the Research Association. The Institute is indebted to the Research Association for valuable financial support of the service which it now provides for the benefit of members of both organizations.

Before the final reorganization of the Information Department was decided, the Information Officer visited a number of other Libraries and Information Departments with a view to examining the various systems already in use. Among these he paid a visit, in October 1946, to the Library of the Verein Deutscher Eisenhüttenleute, in Düsseldorf, whose information service had a considerable reputation before the war. With the co-operation of Herr H. Dickmann the system in operation at that Library was investigated in detail and the opportunity was taken to examine the Universal Decimal Classification.

The problem of deciding upon the best means of classifying technical information presented some difficulty. There was no completely satisfactory system available and if a new system were devised to meet the special case, apart from the time taken to develop it, it could only be proved by actual experience, and unforeseen difficulties might well have rendered it unworkable after a few months. In the circumstances it was felt that the best system available was the Universal Decimal Classification. This has the advantages of being internationally recognized and of being capable of indefinite expansion to meet new technical and industrial developments. No complete up-to-date English edition of the Metallurgical and Engineering Sections was available but the Institute obtained copies of the latest German editions. The Section on Metallurgy (Section 669) has been translated by the Institute and forwarded to the British Standards Institution for consideration by the appropriate committee with a view to its adoption as the official English edition.

The Information Department, organized as outlined above, has been functioning since the beginning of the year and has now reached the stage where the technical index has assumed reasonable working proportions. It is now possible to answer queries on technical literature, particularly literature appearing within the last five or six years, without undue delay, and bibliographies can be prepared reasonably quickly and at short notice. The other branches of the Information Service are not yet so highly developed but it is hoped to be able to give more attention to these in the immediate future.

The efficiency of the service will increase with the number of calls that are made upon it and it is hoped that Members will not hesitate to make free use of the services offered. Any suggestions that Members care to make, with a view to improving the Information Service, will be welcomed, and the Information Officer and Assistant Information Officer hope to take early opportunities of obtaining Members' views by personal contact.

## NEWS OF MEMBERS

▶ Mr. S. P. CHATTERJEE has sailed for India to join the Steel Corporation of Bengal.

▶ Mr. G. C. ELLIS, B.Sc., has left the Ministry of Supply to join the Armament Research Department, Woolwich.

▶ Mr. K. W. J. BOWEN, B.Sc., has left the Billingham Division of Imperial Chemical Industries, Ltd., to begin research work at the Goldsmiths' Laboratory, University of Cambridge.

▶ Mr. H. J. AXON is joining the Metallurgy Section of the Associated Electrical Industries Laboratory, Aldermaston.

▶ Mr. H. R. TIPLER has been appointed Assistant Experimental Officer in Metallurgical Research at the National Physical Laboratory, Teddington (Metallurgy Division).

▶ Mr. J. A. MANNIFIELD has been appointed Chief Works Engineer to the Millom and Askam Hematite Iron Co., Ltd., Cumberland.

▶ Mr. V. SUBRAMANIAM has left the Sales Department of the Tata Iron and Steel Co., Ltd., Calcutta, to join the staff of the Department of Metallurgical Engineering, Columbia University, New York, N.Y., U.S.A.

▶ Mr. P. H. NELSON has been released from H.M. Forces and has returned to the Department of Research and Technical Development of Stewarts and Lloyds, Ltd., Corby.

▶ Mr. ANTON DE SALES BRASUNAS has taken up a post in the Department of Metallurgy of the Massachusetts Institute of Technology, Mass., U.S.A.

▶ Mr. A. L. CARR has left the Department of Metallurgy, University College, Cardiff, to take up an appointment with The Mond Nickel Co., Ltd., Research and Development Department, Birmingham.

▶ Dr. N. STEPHENSON has left the Department of Applied Science at the University of Sheffield to take up a position in the Metallurgy Department of the Ministry of Supply National Gas Turbine Establishment, Leicester.

▶ Mr. T. B. HORWOOD has resigned from the staff of the Metallurgy Division of the National Physical Laboratory, and has taken up an appointment with the British Iron and Steel Research Association.

▶ Mr. G. P. ELSON has transferred from the Sheffield Works of Thomas Firth and John

Brown, Ltd., to the Scunthorpe foundry of the company, where he is a Metallurgist.

▶ Mr. P. H. KUTAR has been appointed Works Manager of the Tata Iron and Steel Co., Ltd., on the retirement of Mr. A. A. BRYANT.

▶ Mr. P. W. SMITH has joined the O. and F. Co., Hobart, Tasmania, as Chief Chemist.

▶ Mr. W. H. GOODLAD has been promoted to Assistant Chief Engineer in charge of Flat Rolling-Mill design, and Mr. J. G. FRITH to Assistant Chief Engineer in charge of the design of Hydraulic machinery, at Messrs. Davy and United Engineering Co., Ltd., Sheffield. These appointments are additional to those of Mr. POOLE, Mr. FRANKLIN and Mr. CRAIG, reported in the August issue of the *Journal*.

▶ Dr. J. M. FERGUSON has been appointed Works Manager of the Dalzell Steel Works, Motherwell.

▶ Sir CHARLES BRUCE-GARDNER, Bt., has been appointed Chairman, and Mr. E. C. LYSAGHT, Mr. E. J. PODE, Capt. H. L. DAVIES, C.B.E., and Mr. R. W. PERRY, M.B.E., have been made Directors of the Lysaght Works of the Steel Company of Wales.

▶ Mr. W. F. CARTWRIGHT has been appointed General Manager, Steel Division, and Mr. T. O. LEWIS has been appointed General Manager, Tinplate Division, of the Steel Company of Wales.

▶ Mr. D. C. WYLIE has been made Plant Manager of the Lanarkshire Steel Works, Motherwell.

▶ Mr. V. J. DONNELLY has returned to S. Africa to set up his own business of jig and tool making, heat-treatment and electro-plating. He will also act as Consulting Metallurgist to National Bolts and Rivets, Ltd., Ophirton, Johannesburg.

▶ Mr. S. WALSH has joined the Research Department of Taylor Brothers and Co., Ltd., Manchester.

▶ Mr. E. HUNTER has been appointed Manager of the Foundry Equipment Department of the Incandescent Heat Co., Ltd.

### Awards

▶ Mr. W. S. WALKER has been awarded the Ph.D. degree of Manchester University.

▶ Mr. E. C. SMITH has been awarded a Doctor of Science degree by the Case Institute of Technology, Cleveland, Ohio, U.S.A.

▶ Mr. J. D. HAWORTH has been awarded the degree of B.Met. with First-class Honours and also has received the Mappin and Westhill Medals from the University of Sheffield. Mr. Haworth has now joined the staff of the Inorganic Chemistry Laboratory, University Museum, Oxford.

▶ Mr. LOUGHNAN ST. L. PENDRED, O.B.E., has been made a Fellow of the City and Guilds of London Institute.

▶ Mr. E. W. SENIOR has been elected Master Cutler for 1947–1948.

▶ Mr. B. L. AVERBACH has been awarded the degree of Sc.D. in Metallurgy by the Massachusetts Institute of Technology. He has accepted an appointment as Assistant Professor of Metallurgy at the Institute.

### Elections

▶ Mr. T. S. WASHBURN has been elected Chairman of the Iron and Steel Division of the American Institute of Mining and Metallurgical Engineers.

### Obituary

The Council regret to record the death of:

Colonel J. S. TRINHAM, Director of N. Hingley and Sons, Dudley, on 25th August, 1947.

JAMES R. GARNER, Managing Director of Howell and Co., Ltd., Sheffield, on 21st September, 1947.

Mr. JOHN LESLIE TOFT, Works Chemist at the Lancashire Steel Corporation, Ltd.

## CONTRIBUTORS TO THE JOURNAL

The late **A. H. Jay, Ph.D.,** was educated at the Nelson Secondary School and at Manchester University, and graduated in the Honours Physics School in 1928. He was awarded the degree of M.Sc. in 1931, and, after a further two years' work, the degree of Doctor of Philosophy. During the latter period he held the Priestley Scholarship and the Beyer Fellowship, and a research grant from the Metropolitan-Vickers Electrical Co., Ltd.

Dr. Jay joined the Central Laboratories of the United Steel Companies, Ltd., in October, 1943, where he remained until his death in February, 1947.

**J. A. Wheeler, Ph.D.**—Leader of a research team, working on behalf of the British Welding Research Association, in the Department of Metallurgy, University of Birmingham. He was educated at the County High School, Redditch, Worcestershire, where he was awarded a County Major Scholarship in 1938, which enabled him to enter the University of Birmingham. In 1941 he took a first-class honours degree in metallurgy and was also awarded a William Gibbins Research Scholarship. He was awarded a Wiggin Post-graduate Scholarship in 1942 and later he received an A. E. Hills Scholarship. Dr. Wheeler started his work with the British Welding Research Association in 1945.

**M. A. Jaswon, B.A., B.Sc.**—Research worker on behalf of the British Welding Research Association, in the Department of Metallurgy, University of

J. A. Wheeler

M. A. Jaswon

W. L. Kerlie

Birmingham. Mr. Jaswon received his early education at Wesley College, Dublin. He entered Dublin University, where he took an honours degree in mathematics and theoretical physics, in 1944, and more recently he has qualified for the M.Sc. degree of the University of Birmingham. He has been working with Dr. Wheeler on welding problems since 1945.

**W. L. Kerlie, B.Sc.**—Technical Development Metallurgist of Messrs. Stewarts and Lloyds, Ltd., Corby. Mr. Kerlie received his training at Glasgow University and at the Royal Technical College, Glasgow. He joined the Research Department of Messrs. Stewarts and Lloyds, Ltd., in 1934, where he was primarily engaged in research problems relating to steel manufacture. During the late war he was appointed Assistant Manager of the Basic Bessemer and Electric Furnace Department at Corby, and has now rejoined the Department of Research and Technical Development.

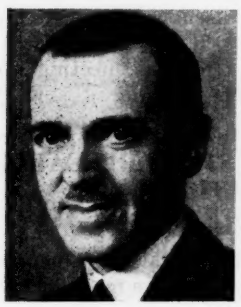
**Ir. J. E. de Graaf**—Head of Laboratories and Research at the Royal Netherlands Blast-Furnaces and Steelworks, Ltd., Ijmuiden. Mr. de Graaf was born in Deventer, Holland, in 1910, and was educated at Amersfoort and Utrecht secondary schools, the Technical College at Amsterdam, and the Technical University at Delft, where he graduated in 1934.

Mr. de Graaf took up the post of X-ray physicist at Philips, Eindhoven, in 1934, and since then he has published work on the use of X-rays in the diagnosis of flaws in welds and castings, a new tube for diffraction investigations, and absorption of gases by metals. He took up his present position in 1941.

**W. Barr, A.R.T.C., F.I.M.**—Chief Metallurgist at Colvilles, Ltd., and a Director of the Fullwood Foundry Co., Ltd. Mr. Barr was born in Larkhill, Lanarkshire, and educated at the Hamilton Academy and the Royal Technical College, Glasgow, where he gained his Diploma in Metallurgy in 1921, and his Associateship in the following year. In 1922 he joined the staff of the Dalzell Works of Colvilles, Ltd., as a metallurgist, and was appointed to his present position in 1936.

During his long service with Colvilles Mr. Barr has contributed articles and papers to numerous societies, and has become a well-known figure in the metallurgical world. In 1944 he was asked to take part in the founding and organizing of the Institution of Metallurgists, of which body he is a Founder Fellow and a Member of Council. He is also a Member of Council of the West of Scotland Iron and Steel Institute.

In 1942 he was a member of a mission sent by the Government to investigate the production of armour plate in the United States of America.



W. Barr

A. J. K. Honeyman

W. W. Franklin

P. F. Grove

**A. J. K. Honeyman, B.Sc., A.R.T.C., F.I.M.**—Deputy Chief Metallurgist at Colvilles, Ltd., Glasgow. Born in 1894, Mr. Honeyman was educated in Glasgow at Hutcheson's Grammar School, the University, and the Royal Technical College, where he graduated in 1921 with special distinction in Metallurgy of Iron and Steel, and where he was awarded an Associateship in 1922. Mr. Honeyman gained his early industrial experience with the Clyde Alloy Steel Co., and at the Dalzell Works of Colvilles, Ltd., Motherwell, and was appointed Test Manager for this company in 1928. In 1938 he was appointed Assistant Chief Metallurgist at the Glasgow offices, and in 1947 he took up his present appointment.

As a Member of the Iron and Steel Institute, Mr. Honeyman contributed to the Symposium on the Hardenability of Steel and has published several papers in the *Journal of the West of Scotland Iron and Steel Institute*. He serves on a number of committees of the British Standards Institution and sub-committees of the British Iron and Steel Research Association.

**Mrs. C. F. Tipper, M.A., D.Sc.**—Metallurgist in the Engineering Laboratory, University of Cambridge. Mrs. Tipper is more widely known under her maiden name, C. F. Elam. She was educated at Newnham College, Cambridge, and at the Royal School of Mines, South Kensington. She graduated with an M.A. degree at Cambridge and received her D.Sc. degree from London University.

As Miss Elam she is well known for her earlier work on plastic deformation of metal crystals, undertaken with the late Professor Harold Carpenter, F.R.S., and Professor G. I. Taylor, F.R.S. After marrying the late G. H. Tipper, M.A., she took part in the Geological Survey of India, and later carried on research work at the Engineering Department of the University of Cambridge. During the war Mrs. Tipper undertook all the teaching of metallurgy in the Department and the heat-treatment for the workshops.

Since 1943 she has been working under the direction of Professor J. F. Baker, O.B.E., M.A., D.Sc., for the Admiralty Ship-Welding Sub-Committee, her investigations on the fracture of mild steel forming part of the research on welded structures.

**W. W. Franklin, A.M.I.Mech.E.**—Chief Engineer, Davy and United Engineering Co., Ltd. Mr. Franklin served his apprenticeship in the works of Davy Brothers Limited, Sheffield, completing his training in the drawing office, where he remained as a leading designing draughtsman until 1931, when he was appointed Assistant Engineer. From 1937 to 1942 he continued with the Company, which had now become Davy and United Engineering Co., Ltd., as Manager of the Technical Department concerned with rolling mills of all classes.

In 1942 he was appointed Manager of the Technical Department, known as the Proposal Department, responsible for engineering layout and design of all tenders submitted. Mr. Franklin took up his present position in 1947, and now controls the Company's engineering activities in connection with heavy steelworks plant, including rolling mills, high-speed forging presses, and hydraulic machinery of all types.

**P. F. Grove, M.A., M.I.E.E.**—Chief Electrical Engineer to John Miles and Partners (London), Ltd. Mr. Grove received his technical education at Cambridge University, and after serving an apprenticeship with the English Electric Co., Ltd., at Stafford, he was appointed to the rolling-mill section of the same company.

In 1928 he joined the firm of Messrs. Kennedy and Donkin, and was engaged on the design and construction of a large part of the British grid system. From 1936 to the present time Mr. Grove has been Chief Electrical Engineer to H. A. Brassert and Co., Ltd., and their successors, John Miles and Partners (London), Ltd. During this period he has been responsible for several comprehensive electrical installations in the iron and steelworks field, notably the extensions to Corby in 1936, and the iron and steelworks electrification and power supply at Ebbw Vale, completed before the war.

## IRON AND STEEL ENGINEERS GROUP

The **Fifth Meeting** of the Iron and Steel Engineers Group will be held at 4, Grosvenor Gardens, London, S.W.1, on Wednesday, 26th November, 1947.

At the morning session, Mr. W. W. Franklin and Mr. P. F. Grove will present for discussion a paper on "*The Mechanical and Electrical Features of the Primary Hot-Rolling-Mill Auxiliaries.*

After a Buffet Luncheon, to be held in the Library, the afternoon session will be devoted to the presentation and discussion of a paper on "*Modern Small Rolling Mills*" by Mr. G. A. Phipps. The two papers for this meeting are published in this issue of the *Journal*.

## BRITISH IRON AND STEEL RESEARCH ASSOCIATION

### Research on Wire Drawing

A "brake on production" that may increase the output of steel is the feature of a machine now installed in a Sheffield works.

This is a prototype back-pull wire-drawing

machine (manufactured by Marshall Richards and Company) which is in operation at the works of Arthur Lee and Sons, who have agreed to allow the British Iron and Steel Research Association to have experimental use of it for the first twelve months of its life.

In back-pull drawing a tensile stress is applied to the wire before it enters the die, and the electrical equipment of the experimental machine is designed to effect this. It is believed that the application of back pull will result in prolonged die life or the possibility of heavier (and therefore fewer) reductions.

Experiments already begun by BISRA, which will continue over the next year, are designed to assess the value of back-pull wire drawing under industrial conditions. Hitherto investigation has been confined to theoretical calculation and experiments on a laboratory scale.

Arthur Lee and Sons have also placed servicing facilities for the machine at BISRA's disposal, affording a fine example of the close relationship in the steel industry between research and industrial application.

## INSTITUTION OF METALLURGISTS

### A Metallurgical Adventure

The Institution of Metallurgists held their first Refresher Course for metallurgists from 5th to 7th September, and it is hoped that such gatherings will become a regular feature of metallurgical practice.

In the beautifully appointed L.M.S. School of Transport in Derby some 700 members of the Institution, representing all grades of membership, lived and worked together over the week-end. The theme of the studies was "*The Transformations in Solid Metals and Alloys*," and the following lectures were given and informal discussion took place :

Lecture 1—A general review of the subject, by Professor F. C. Thompson, M.Sc., D.Met. (Manchester University)

Lecture 2—"The Transformation of Austenite in Steels," by Professor J. H. Andrew, D.Sc. (Sheffield University)

Lecture 3—"The Determination of Time–Temperature–Transformation Curves in Steels," by E. H. Bucknall, M.Sc. (Mond Nickel Co., Ltd.)

Lecture 4—"The Practical Aspects of Austempering, Martempering and other Treatment for Steels," by J. Shaw, B.Sc. (Wm. Jessop and Sons, Ltd.)

Lecture 5—"The Formation of Graphite in Cast Iron and Related Alloys," by J. G. Pearce, M.Sc. (British Cast Iron Research Association)

Lecture 6—"Atomic Changes in Solid Solutions, including Age Hardening," by G. V. Raynor, M.A., Ph.D.

Lecture 7—"Order–Disorder Transformations in Solid Solutions," by G. V. Raynor, M.A., Ph.D. (Birmingham University)

While the newer physical methods of approach to problems of transformation had a good deal of attention, it was apparent that there is still room for further development and greater use of the more classical methods of the older school of metallurgists in the study of this subject.

All present were convinced that this type of meeting is likely to play a most important part in the future work of the Institution.

### Cancellation of Members Luncheons

Owing to the recent announcement made by the Government, in connection with the catering trade, the Council has regretfully decided that the first Members Luncheon, which was to take place on the 29th October, 1947, will have to be cancelled.

The Council had in mind arranging further provincial meetings later this year or early in 1948 : it now appears that travelling may be somewhat difficult in this period and industrial rearrangements caused by the spread of power loads may be such that many Members could not possibly attend such meetings if arranged. It has been decided therefore to leave the question of further meetings until the early spring.

## AFFILIATED LOCAL SOCIETIES

### Sheffield Society of Engineers and Metallurgists

The new list of Officers for the session 1947–1948 is as follows :

**President**

AMBROSE FIRTH
(To 31st December, 1947)

**Vice-Presidents**

G. BAKER
B. W. DONCASTER
J. H. G. MONYPENNY
E. W. SENIOR
Professor H. W. Swift, M.A., D.Sc.

**Hon. Treasurer**

L. K. EVERITT, B.Met.

**Hon. Secretary**

E. J. THACKERAY

**Members of Council**

M. BROWN
E. D. BOOL
H. BULL
H. H. BURTON
L. K. EVERITT, B.Met.
R. E. S. FISHER
E. GREGORY, Ph.D.
G. E. GILFILLAN
W. R. MADDOCKS, B.Sc., Ph.D.
D. A. OLIVER
Professor R. J. SARJANT, D.Sc.
C. SYKES, D.Sc., F.R.S.

The lecture programme for the new session is given below :

**1947**

13th Oct.—"*High-Speed Photography*," by G. A. Jones (Research Laboratory, Messrs. Kodak, Ltd., Harrow, Middx.)



XUM

24th Nov.—Thomas Hawksley Lecture, "*The Rocket as a Weapon of War*," by Sir Alwyn Crow, C.B.E. (Joint Meeting with the Yorkshire Branch, Institution of Mechanical Engineers).

15th Dec.—Symposium on "*The Use of Liquid Fuel in Open-Hearth Furnaces.*"

1948

19th Jan.—Joint Meeting with the Engineers Group, Iron and Steel Institute.

23rd Jan.—"*Some Metallurgical Problems in the Field of Atomic Energy*," by E. W. Colbeck, M.A. (Joint Meeting with the Sheffield Section, Institute of Metals).

16th Feb.—Exhibition of Technical Films, by arrangement with the Iron and Steel Institute.

15th Mar.—"*The Cold-Working of Metals*," by Dr. C. H. Desch, F.R.S. (President, Iron and Steel Institute).

13th Apr.—"*Thin Films on Metals*," by Dr. Ulick R. Evans, M.A. (Cambridge University). (Joint Meeting with the Sheffield Metallurgical Association).

All Meetings will be held at the Royal Victoria Station Hotel, Sheffield, and will commence at 6.15 P.M.

## Newport and District Metallurgical Society

The following Officers have been elected for the new session 1947–1948 :

**President**

G. H. LATHAM

**Vice-Presidents**

Professor W. R. D. JONES, D.Sc. G. D. SHOWELL, B.Sc.
R. PERRY, O.B.E. F. W. R. HARRISON, B.Sc.
JOHN MYERS

| Hon. Treasurer | Joint Hon. Secretaries |
|---|---|
| H. R. DAVIES | T. G. GREY-DAVIES |
| | E. WILLIAMS |

**Members of Committee**

Dr. BRYN JONES (Chairman) J. A. LINNEY
H. H. STANLEY A. C. BARNES
F. J. PRATT W. F. GREEN
F. KING C. WIPPERMAN
A. H. POPLE

The programme of meetings for the first half of the new session is as follows :

1947

11th Oct.—"*Some Deformation Features of Steel*," by Professor Hugh O'Neill, D.Sc., F.I.M. (University College, Swansea).

8th Nov.—"*Electro-Tinning of Steel Strip*," by C. Frenkel (Messrs. John Miles and Partners (London), Ltd.).

13th Dec.—"*Forged Steel Rolls*," by A. H. Waine (Messrs. Hadfields, Ltd).

Meetings are held in Newport Technical College on the second Saturday in each month, commencing at 6.30 P.M.

## Swansea and District Metallurgical Society

MEMBERS OF COUNCIL

In addition to the list of members published in the August News Section (page 569), Mr. F. Mills and Mr. M. J. A. Thomas, B.Sc., have been co-opted Members of Council.

# NEWS OF SCIENCE AND INDUSTRY

## Refractories

The Department of Applied Chemistry of the Northampton Polytechnic has arranged a course of lectures on "*Refractories, their Production, Properties and Uses*," to be delivered by L. R. Barrett, B.A., B.Sc., M.S.

The lectures are being given on Wednesday evenings at 7 P.M., commencing on 8th October, and continuing until 10th December, 1947. The fee for the course is 12*s.* 6*d.*, and admission is effected by personal enrolment at the Polytechnic Office, St. John Street, London, E.C.1.

## Royal Society of Arts

H.R.H. The Princess Elizabeth has graciously accepted the invitation of the Royal Society of Arts to become its President.

The Royal Family has been closely connected with the Royal Society of Arts for over a hundred years. Prince Albert became the Society's President in 1843, and in that capacity initiated the Great International Exhibition held in Hyde Park in 1851. Other Royal Presidents have been their Royal Highnesses The Prince of Wales (later King Edward VII), The Prince of Wales (later King George V) and The Duke of Connaught.

The Society is the third oldest of the learned Societies in Britain, and will shortly prepare to celebrate its second centenary in July, 1954.

## The Industrial Future of Great Britain

The University of London and the Institute of Bankers have arranged a course of fifteen weekly lectures and discussions on "*The Industrial Future of Great Britain*," commencing on Tuesday, 4th November, 1947.

The course is designed as a study of the possibilities and prospects of rebuilding British industry in the light of our present national economy and

the development of an export trade far in excess of previous efforts.

The series of lectures is divided into two parts. The first part is intended as a study of the necessary bases of reconstruction for industry: the second part is specially concerned with the need for export and the consequences of this need. The course will be opened on 4th November with a lecture by Professor T. S. Ashton, M.A., on "*The Industrial Past*," which will be followed by lectures on various industrial topics on each Tuesday until 2nd March, 1948. Of particular interest to Members of the Iron and Steel Institute will be the lecture on "*Iron and Steel*" by Robert Stone, M.A., M.Eng., to be given on 20th November, and the lecture on "*Fuel and Power*" to be given on 9th December.

The meetings will be held at the Beaver Hall of the Hudson's Bay Company, Garlick Hill, E.C.4. The fee for the course of fifteen lectures is one guinea, and applications for tickets should be made to the Secretary, Institute of Bankers, 11, Birchin Lane, E.C.3.

## CORRIGENDA

### Hydrogen in Steel

The following corrections should be noted to the paper "*Hydrogen and Transformation Characteristics in Steel*" by J. H. Andrew, H. Lee, H. K. Lloyd, and N. Stephenson which was published in the June issue of the *Journal*:

Page 222, Equation (3) should read:

$$\frac{dV}{dt} = q = \frac{2CD}{r}\left[e^{\frac{-5\cdot8Dt}{r^2}} + e^{\frac{-30\cdot5Dt}{r^2}} + e^{\frac{-75\cdot0Dt}{r^2}} + \ldots\ldots\right] \ldots(3)$$

Page 222, Equation (5) should read:

$$\frac{1}{C}\frac{dV}{dt} = \frac{4\pi D}{L^2}\left[e^{\frac{-D\pi^2t}{L^2}} - 3e^{\frac{-9D\pi^2t}{L^2}} + 5e^{\frac{-25D\pi^2t}{L^2}} - \ldots\ldots\right] \ldots(5)$$

Page 238, column 1, last line: "tetragonal" should read "trigonal."

### News of Members

In the News Section of the August issue of the *Journal* (page 565, Elections): "Mr. F. E. Stockeld" should read "Mr. F. E. Stokeld."

## DIARY

**24th October**

INSTITUTION OF MECHANICAL ENGINEERS—Presidential Address—Storey's Gate, S.W.1, 5.30 P.M.

**29th October**

INSTITUTE OF WELDING—Presidential Address by J. L. Adam—Institution of Civil Engineers, London, 6.0 P.M.

**31st October**

INSTITUTION OF MECHANICAL ENGINEERS—Discussion on "*The Manufacture of Turbine Blades for the Whittle Engine*," by T. A. Kestell—Storey's Gate, S.W.1, 5.30 P.M.

**3rd November**

CLEVELAND INSTITUTION OF ENGINEERS—Annual General Meeting and Lecture on "*Development and Utilization of Stainless Steels*," by W. W. Stevenson—Scientific and Technical Institute, Corporation Road, Middlesbrough, 6.30 P.M.

**4th November**

SHEFFIELD METALLURGICAL ASSOCIATION—Discussion on "*Hydrogen in Steel Manufacture*," by C. Sykes, H. H. Burton, and C. C. Gegg, and on "*Hydrogen and Transformation Characteristics in Steel*," by J. H. Andrew, H. Lee, H. K. Lloyd, and N. Stephenson (Joint Meeting with the Iron and Steel Institute)—198, West Street, Sheffield, 7.0 P.M.

**6th November**

LEEDS METALLURGICAL SOCIETY—"*Magnesium Alloys*," by Dr. F. A. Fox—Main lecture theatre of the Chemistry Department, The University, Leeds, 7.0 P.M.

**8th November**

NEWPORT AND DISTRICT METALLURGICAL SOCIETY—"*Electro-Tinning of Steel Strip*," by C. Frenkel—Newport Technical College, 6.30 P.M.

**12th–13th November**

IRON AND STEEL INSTITUTE—Autumn Meeting—4, Grosvenor Gardens, S.W.1, 10.0 A.M.

**15th November**

SWANSEA AND DISTRICT METALLURGICAL SOCIETY—"*Metal Surfaces*," by M. R. Hopkins—The Royal Institution of South Wales, Swansea, 6.30 P.M.

**18th or 25th November**

LINCOLNSHIRE IRON AND STEEL INSTITUTE—Lecture on "*Oil Firing of Open-Hearth Furnaces*," by S. W. Evans—Technical School, Cole Street, Scunthorpe, 7.30 P.M.

**24th November**

SHEFFIELD SOCIETY OF ENGINEERS AND METALLURGISTS—Thomas Hawksley Lecture, "*The Rocket as a Weapon of War*," by Sir Alwyn Crow, C.B.E. (Joint Meeting with the Yorkshire Branch, Institution of Mechanical Engineers), —Royal Victoria Station Hotel, Sheffield, 6.15 P.M.

**26th November**

MANCHESTER METALLURGICAL SOCIETY—"*Some Metallurgical Problems in the Field of Atomic Energy*," by E. W. Colbeck (Joint Meeting with Iron and Steel Institute and Institute of Metals)—Engineers' Club, Albert Square, Manchester, 6.30 P.M.

**26th November**

IRON AND STEEL ENGINEERS GROUP—Fifth Meeting on "*Rolling-Mill Auxiliaries*,"—4, Grosvenor Gardens, S.W.1.



XUM

## TRANSLATION SERVICE

Since the announcement made in the September issue of the *Journal* (*see* page 138), further translations have been put in hand and the following are now available or in course of preparation.

### TRANSLATIONS AVAILABLE

No. 320 (German). W. KOENNECKE : "New Nozzle Designs for Low and Medium Reynolds Numbers." (*Forschungen aus dem Gebiete des Ingenieurwesens*, 1938, vol. 9, pp. 109–125).

No. 321 (Swedish). E. SUNSTRÖM : "The Development of the Electric Steel Furnace during The World War 1939–45." (*Jernkontorets Annaler*, 1946, vol. 130, No. 10, pp. 477–549).

### TRANSLATIONS IN COURSE OF PREPARATION

(German). W. BADING : "The Development of Basic Converter Practice." (*Stahl und Eisen*, 1947, vol. 66–67, Apr. 24, pp. 137–149 ; May 22, pp. 180–186 ; June 19, pp. 212–223).

(German). P. BARDENHEUER and W. GELLER : "The Basic Principles of the Desulphurization of Pig Iron and Steel." (*Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1934, vol. 16, No. 7, pp. 77–91). (Translation provided through the courtesy of Mr. G. L. Evans, University College of Swansea).

(Swedish). E. BERNHULT : "The Yield Point in Bending and the Stress Distribution in Bars and Tubes in Plastic Bending." (*Jernkontorets Annaler*, 1943, vol. 127, No. 16, pp. 491–533).

(German). W. EILENDER and W. ROESER : "Metallurgical Investigations on the Working of the Basic-Bessemer Process with Oxygen-Enriched Blast." (*Stahl und Eisen*, 1939, vol. 59, Sept. 21, pp. 1057–1067).

(German). A. GELEJI : "The Theoretical Problems Involved in the Design of Rolling-Mill Stands." (*Royal Hungarian Palatine-Joseph University, Publications of the Department of Mining and Metallurgy*, 1941, vol. 13, pp. 224–242).

(German). A. GELEJI : "Calculating the Forces Arising and the Power Requirements in the Mannesmann Tube-Rolling Process." (*Royal Hungarian Palatine-Joseph University, Publications of the Department of Mining and Metallurgy*, 1941, vol. 13, pp. 208–223).

(French). R. GIRSCHIG : "A New Micro-Hardness-Tester. The L.C. Microsclerometer." (*Revue de Métallurgie*, 1946, vol. 43, Mar.–Apr.).

(Russian). M. A. GLINKOV and V. C. KOCKO : "On the Question of Heat Transfer in a Molten Bath by Gas Bubbles." (*Bulletin de l'Académie des Sciences de l'URSS Classes des Sciences Techniques*, 1946, No. 10, pp. 1463–1472).

(German). G. F. HÜTTIG : "The Theoretical Basis of Sintering Processes in Powders." (*Metallwirtschaft*, 1944, vol. 23, Oct. 20, pp. 367–372).

(French). P. LAURENT : "Contribution to the Theory of the Plasticity of Metals and Alloys." (*Revue de Métallurgie*, 1945, vol. 42, Mar., pp. 72–92 ; Apr., pp. 125–132 ; May, pp. 156–167 ; June, pp. 194–203 ; July, pp. 230–239).

(Swedish). S. MÖRTSELL : "Rationalization in Swedish Iron Ore Dressing." (*Jernkontorets Annaler*, 1946, vol. 130, No. 9, pp. 369–460).

(German). A. POMP and W. PUZICHA : "The Cold-Rolling of High-Tensile Strip Steels and Their Properties." (*Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1943, vol. 26, No. 2, pp. 13–16).

(German). K. RUMMEL : "The Gas Balance in Iron and Steel Works." (*Stahl und Eisen*, 1947, vol. 66–67, Jan. 2, pp. 19–23).

(German). E. SIEBEL : "Present Knowledge of the Mechanics of Wire Drawing." (*Stahl und Eisen*, 1947, vol. 66–67, May 22, pp. 171–180).

(Russian). F. F. VITMAN, N. N. DAVIDENKOV and N. A. ZLATIN : "Cold-Brittleness of Steel in Torsion." (*Journal of Experimental and Theoretical Physics, U.S.S.R.*, 1940, vol. 10, Nos. 9–10, pp. 1137–1145).

CHARGES FOR COPIES OF TRANSLATIONS.—For the above Translations a charge will be made of 10*s*. for the first copy and 5*s*. for each additional copy of the same translation. Requests should be accompanied by a remittance. The above translations are not available on loan from the Joint Library.

TRANSLATIONS PREPARED AT MEMBERS' REQUEST.—Members requiring translations of foreign papers are invited to communicate with the Secretary, who will ascertain whether the translations can be prepared for inclusion in the series.

# ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

CONTENTS


| | PAGE |
|---|---|
| FUEL—PREPARATION, PROPERTIES, AND USES | 289 |
| REFRACTORY MATERIALS | 290 |
| PRODUCTION OF STEEL | 291 |
| FOUNDRY PRACTICE | 292 |
| HEAT-TREATMENT AND HEAT-TREATMENT FURNACES | 294 |
| LUBRICANTS AND LUBRICATION | 295 |
| WELDING AND FLAME-CUTTING | 296 |
| MACHINING AND MACHINABILITY | 297 |
| POWDER METALLURGY | 298 |
| PROPERTIES AND TESTS | 299 |
| METALLOGRAPHY | 311 |
| CORROSION | 314 |
| ANALYSIS | 317 |
| MISCELLANEOUS | 318 |
| BOOK NOTICES | 319 |
| NEW PUBLICATIONS | 320 |


## FUEL—PREPARATION, PROPERTIES, AND USES

**Photographic Techniques in Combustion Research.** L. Beral and W. T. Cooper. (Monthly Bulletin of the British Coal Utilisation Research Association, 1947, vol. 11, Apr., pp. 105–117). The photographic methods which have been widely applied to the study of combustion in fuel beds and flame phenomena are discussed. Photographic technique has been applied to the study of flames in the open-hearth furnace by Chesters and Philip and their work is reported in Iron and Steel Institute Special Report No. 37.—R. E.

**Notes on Recent Developments in Fuel Technology.** W. A. Kirby. (Fuel, 1947, vol. 26, Mar.–Apr., pp. 25–28). Recent literature on fuel and power in the U.S.S.R., the brown coals of Victoria, the constitution of torbanite, combustion in gas turbines, and other subjects related to fuel technology is reviewed.—C. O.

**Possibilites for the Extended Use of Oxygen in the British Iron and Steel Industry.** M. W. Thring. (Journal of the Iron and Steel Institute, 1947, vol. 156, June, pp. 285–291). The economic aspects of the use of oxygen in the blast-furnace and for steelmaking are considered. Recent developments in methods of manufacturing oxygen in the purity ranges of 80–100% and 40–60% make its use for the combustion of fuel in the steel industry a very important practical possibility. If the capital cost of building a plant to produce 200 tons of oxygen per day were faced it would be likely to give an overall economy of fuel if applied to a furnace producing ferromanganese. The use of oxygen in the open-hearth furnace is only of interest if (*a*) the use of oxygen is confined to the "critical period" of the melt and (*b*) the oxygen-enriched air is introduced, not with the main air stream, but in such a way that it gives greatly improved mixing and combustion conditions.—R. A. R.

**Combustion Systems and Burners.** H. Schramm. (Steel Processing, 1947, vol. 33, Apr., pp. 234–239; May, pp. 304–307). Several designs of high-pressure and low-pressure gas burners for industrial furnaces are described and illustrated.—R. A. R.

**Some Technical Aspects of Oil-Firing Industrial Furnaces.** G. R. Bashforth. (Metallurgia, 1947, vol. 36, June, pp. 57–62). The characteristics of oil as a fuel and the technology of oil-firing industrial furnaces are discussed. Reference is made to furnace and burner design and the use of tar and tar oils.—C. O.

**Developments in the Use of Blast-Furnace Gas at the Port Kembla Steelworks.** H. Escher. (Journal of the Iron and Steel Institute, 1947, vol. 156, May, pp. 1–27). A comprehensive account is given of the use of blast-furnace gas at Port Kembla steelworks, New South Wales. The paper deals with some aspects of blast-furnace-gas supply and regulation, with developments in the use of this fuel for heating steel, and with the effects of these changes on overall fuel consumption and on steelworks practice in general.—R. A. R.

**Moisture in Flue Gases.** R. H. Parsons. (Power and Works Engineering, 1947, vol. 42, June, pp. 162–164). A short explanation is given of a method of using the results of an ordinary Orsat test to calculate the amount of heat carried away by water vapour in flue gases.—C. O.

**Coal Cleaning.** (Scope, 1947, Jan., pp. 72–81, 118–120). The common methods of coal cleaning are very briefly discussed and the economics of coal cleaning are considered from the viewpoints of both producer and consumer.—C. O.

**Some Problems of Cleaning Small Coals in South Wales.** J. H. Griffiths. (Journal of the Institute of Fuel, 1947, vol. 20, Feb., pp. 99–103, 105). The author discusses the changes which have taken place in the quality of raw coal in South Wales in the past twenty years.

The considerable increase in both the percentage of smalls and the ash content of run-of-mine coal which has been brought about by increasing mechanization and the working of poor seams has resulted in many coal-cleaning plants working with excessive overloads, to the detriment of quality and efficiency. The present methods of using water for dust suppression underground have also created problems, since the free moisture content of small coals is often increased beyond the value at which dedusting, fine screening, and dry-cleaning methods can be operated efficiently. —C. O.

**Experiments in Fleissner Drying Victorian Brown Coal.** J. R. Bainbridge and K. Satchwell. (Fuel, 1947, vol. 26, Mar.–Apr., pp. 28–38). Details are given of experiments in which samples of coal from the Latrobe and Yallourn seams in the Latrobe Valley, Gippsland, Australia, were dried by the Fleissner process. This process involves heating the coal to 200° C. in an atmosphere of saturated steam, under pressure, and then reducing the pressure.—C. O.

**The Russell Test Oven.** (Coke and Gas, 1947, vol. 9, May, pp. 143–144). A description is given of the Russell oven for determining the expansion of coal during coking. —C. O.

**Recent Developments in By-Product Coking.** H. Craddock. (Sheffield Coke Oven and Chemical Trades Technical Society: Coke and Gas, 1947, vol. 9, May, pp. 131–137, 149; June, pp. 175–181). Modern American practice in the heating of by-product coke ovens of the Wilputte, Koppers-Becker, and Simon-Carves types is reviewed. The door assemblies, charging mechanisms, compensating mains, and ammonium-sulphate manufacturing processes of the Wilputte and Koppers ovens are illustrated.—C. O.

**The Distribution of Fuel in Gas Producers.** M. L. Hughes. (Journal of the Iron and Steel Institute, 1947, vol. 156, May, pp. 55–74). A "slice" model technique has been employed to examine the distribution of the fuel in gas producers using various charging methods under varying conditions. By means of photgraphs and graphical diagrams it has been possible to demonstrate the influence on fuel-bed contour and size distribution of: (*a*) The relative diameters of producer body and charging bell; (*b*) the use of a distributing bell in the "open" position as often utilized in conjunction with mechanical charging systems; (*c*) variation of ash-bed height; (*d*) the rolling of the charge within the producer. The improvement possible in producers using hopper-and-bell charging by installing auxiliary intercepting devices is shown. The Morgan feed is shown to produce a more satisfactory distribution with much less size segregation. The height of ash bed is shown to have an appreciable effect. The use of the "flappers" and a disadvantage attached to one of them are discussed. The results obtained by means of slice models have been checked by using circular models. It is demonstrated that for static types there is a small discrepancy at the centre with the slice model, but for the Morgan producer it was found that the slice model gives a misleading result for the central zone of a complete firebed built up from a succession of feeds. This criticism does not apply to its use for the study of the distribution of individual feeds nor to the results obtained at the perimeter or in "no rolling" experiments. Works tests confirm the results given by model experiments for distribution, and conclusions are drawn regarding the probable effect upon gasification.

**Experiments on Gas Flow in Producer-Fuel Beds.** M. L. Hughes. (Journal of the Iron and Steel Institute, 1947, vol. 156, July, pp. 371–379). The slice model of a static producer previously used in work on fuel distribution in fuel beds (*see* preceeding abstract) has now been used to demonstrate the flow of gas through "fuel" beds produced in various ways. The path of the gas is shown to depend mainly on size segregation and the relative porosity of ash bed and fuel bed. Experiments have been carried out to show the effect of bell diameters, the use of deflecting devices, size ratio of charge, gas velocity, ash-bed structure, the presence of wall clinker, and layer charging of two fuels. A multicolour technique combined with colour photography has been tried for the latter.

**Principles and Practice of Producer Gas Manufacture in the Steelworks. Part II—Producer Design and Operation. Part III—Operation and Control.** M. L. Hughes. (Man and Metal, 1947, vol. 24, June, pp. 86–87; July, pp. 102–103). The progress of producer design during the last 25 years, leading to such developments as the Lurgi, Winkler, and "boiling bed" processes and the use of oxygenated blast, is reviewed. The requirements of producer fuel and producer operation and control are discussed.—M. A. V.

## REFRACTORY MATERIALS

**Refractories Industry of Italy.** L. Pompei. (American Ceramic Society Bulletin, 1947, vol. 26, Mar. 15, pp. 88–93). Statistics are presented on the organization of the refractories industry in Italy, the available raw materials and their compositions, and the types of refractories produced. Short descriptions are given of plants, laboratories, and technical organizations connected with the industry, and of two machines for tensile-testing and measuring thermal expansion respectively. —C. O.

**Dolomite Resources in Japan.** (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1159: H.M. Stationery Office). Details are given of the location and extent of the deposits of dolomite in Japan. Almost the whole of the 1945 production of 182,000 metric tons was used as a basic refractory in the iron and steel industry.—C. O.

**The Position and Possibilities Regarding Magnesite.** H. van Thiel. (Technik, 1947, vol. 2, Mar., pp. 105–106). As there are no natural sources of magnesite within the present boundaries of Germany, the manufacture of magnesite refractories from magnesia obtained by chemical methods is now a matter of great importance. The prospects of doing this are briefly reviewed.—R. A. R.

**Process for Manufacture of Dead-Burned Magnesite and Precipitated Calcium Carbonate from Dolomite.** R. D. Pike. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2155: Mining Technology, 1947, vol. 11, Mar.). The problem of discovering and developing an economic process for separating the magnesia and lime of the dolomite of north-west Ohio, and producing each in a form relatively free from the other is discussed and the Harrison-Walker-Pike process for doing this is described and illustrated.—R. A. R.

**Determination of the Resistance of Fireclays to Disintegration by Carbon Monoxide.** S. F. Bohlken. (1946, Amsterdam.) [In Dutch, with English summary]. The researches and conclusions of previous investigations on the disintegrating action of CO on fireclay are reviewed. A new rapid colorimetric method of determining the carbon deposition was developed, as well as a second method in which the carbon was burned to $CO_2$, but neither method gives the complete picture owing to the

irregular distribution of the carbon. Reliable results were obtained by passing a synthetic gas mixture (containing CO 34·5%) over chips of the firebrick at 600–800° C., and determining the $CO_2$ formed. Rapid temperature changes increased the catalytic action of the iron in the firebrick. It was concluded that iron compounds were converted into active catalysts during firing, but Diepschlag and Feist's views of the effect of the elastic compressibility of carbon on disintegration are considered to be only partially correct.—M. A. V.

**Elastic Behavior and Creep of Refractory Brick under Tensile and Compressive Loads.** L. E. Mong. (Journal of the American Ceramic Society, 1947, vol. 30, Mar. 1, pp. 69–78; Journal of Research of the National Bureau of Standards, 1947, vol. 38, Feb., pp. 229–240). Specimens cut from 9-in. bricks of nine brands of fireclay, including two high-alumina, four fireclay, two siliceous fireclay, and one silica, were subjected to tensile and compressive creep tests at eleven temperatures between 25 and 950° C., each test lasting approximately 240 days. The lowest temperatures at which creep was significant were (*a*) 700–850° C. for high-alumina brick, (*b*) 600–700° C. for fireclay brick, and (*c*) 950° C. for siliceous and silica bricks. The results for creep under compressive stress could not be correlated with those under tension. The changes in modulus of elasticity during the tests are recorded.—C. O.

**Special Refractories for Metal Melting.** W. H. Henson. (American Foundrymen's Association, 1947, Preprint No. 47–40). The properties of special refractories used in metal-melting furnaces, in particular silicon carbide, fused alumina and magnesia cements, and zirconium and mullite refractories, are reviewed.—R. A. R.

**Vermiculite Insulating Brick.** R. F. Rea. (American Ceramic Society Bulletin, 1947, vol. 26, Feb. 15, pp. 36–38). The manufacture and properties of the vermiculite insulating brick are discussed. Eyrite, the colloidal magnesium silicate, is a very good bond for fired vermiculite brick; the product containing 25% of eyrite has a linear firing shrinkage of about 3% at 2100° F.—R. A. R.

**A Note on the Application of the Differential Thermal Analysis Method to some Basic Refractory Materials.** T. W. Howie and J. R. Lakin. (Transactions of the British Ceramic Society, 1947, vol. 46, Jan.–Feb., pp. 14–19). The application of the differential thermal analysis method in studies of the constitution of magnesite, dolomite, and chromite products is discussed.—R. A. R.

**Method for Determining Tensile Properties of Refractory Materials at Elevated Temperatures.** J. R. Bressman. (Journal of the American Ceramic Society, 1947, vol. 30, May, pp. 145–152). Equipment for testing ceramic materials at temperatures up to 2000° F. was developed, and a method was devised for evaluating the bending stresses applied by it. The mechanical properties of a sillimanite refractory at different temperatures are given.—R. A. R.

**An X-Ray Study of Some Kaolinite Fireclays.** G. W. Brindley and K. Robinson. (Transactions of the British Ceramic Society, 1947, vol. 46, Mar.–Apr., pp. 49–58). A detailed study is made of the crystal structure of the clay mineral in a number of typical fireclays. Previous thermal-analysis studies which indicated that the mineral is intermediate in character between true kaolinite and true halloysite are now confirmed by X-ray analysis. Although the observed X-ray powder diagram can be interpreted in terms of a monoclinic cell, the symmetry is thought to be only pseudo-monoclinic. Two kinds of randomness are considered, *viz.*, (*a*) randomness in the positions occupied by the aluminium atoms and (*b*) randomness in the displacement of the layers parallel to the *b*-axis, some of which are multiples of $b_0/3$ while others appear to have random values. The relationship between the dissociation temperature and the degree of randomness in kaolin minerals is considered, and the existence of a series of minerals ranging from an ideal kaolinite with a completely ordered arrangement of layers at one extreme, to an ideal halloysite with a completely disordered arrangement at the other, is thought to be possible. Fireclays appear to occupy an intermediate position in such a series.—J. R.

**The Durability of Refractories with Special Reference to the Problem of Slag Attack.** J. White. (Institute of Fuel Bulletin, 1947, June, pp. 117–126). The relationship between the physical properties and the durability of refractories and the chemistry of the action of fluxes on refractories are discussed.—C. O.

**Plastic Refractories.** J. C. Hayman. (Iron and Steel, 1947, vol. 20, Apr., pp. 137–138). Although plastic refractories have many serious limitations, their use might be advantageous in situations where the plastic is fully supported and a good depth of sinter is not essential.—J. R.

**Progress Report on Carbon Linings for Blast Furnaces.** V. J. Nolan. (Blast Furnace and Steel Plant, 1947, vol. 35, Apr., pp. 454–460). Details are given of carbon linings in blast-furnace hearths installed or in process of installation in the United States. The design, durability, and operating characteristics of carbon refractories are discussed in the light of the experience gained in thirteen installations.—J. R.

**Foundry Refractories—Their Properties and Application.** C. A. Brashares. (American Foundryman, 1947, vol. 11, Jan., pp. 41–45). An outline is given of the important properties of the refractories used in foundries, with particular reference to their practical significance.—C. O.

**Refractory Applications for Acid Open-Hearth Furnaces.** R. R. Fayles. (Blast Furnace and Steel Plant, 1947, vol. 35, Feb., pp. 217–218). An account is given of experiments in the use of basic refractories in certain parts of acid open-hearth furnaces, and it is concluded that there is a definite scope for such applications.—J. R.

**German Open Hearth Furnace Refractories.** (Combined Intelligence Objectives Sub-Committee, 1947, File No. XXXIII–57: H.M. Stationery Office). This report is supplementary to the C.I.O.S. Report No. XXXII–119. Particular reference is made to "all-basic" construction.—R. A. R.

**News for the Refractories Industry.** L. Sanderson. (Refractories Journal, 1947, vol. 23, Apr., pp. 133–136). Recent developments in refractory materials for many industrial purposes, including several applications in steelmaking are reviewed.—R. A. R.

## PRODUCTION OF STEEL

**Report on Scrap Preparation for Melting Operations.** (American Iron and Steel Institute, Mar., 1947, Contributions to the Metallurgy of Steel, No. 15). Data obtained from the answers to a questionnaire to American steel melters on their methods of preparing and charging scrap are tabulated.—C. O.

**Furnace Converts Turnings into Heavy Melting Stock.** J. C. Sullivan. (Steel, 1947, vol. 120, June 23, pp. 124–126). A rocker-type oscillating gas- or oil-fired furnace for the treatment of scrap steel is briefly described. In a controlled atmosphere and at high temperatures turnings are converted by the tumbling action into heavy stock, which can be charged into the open-hearth furnace ten times faster than can untreated turnings.—C. O.

**Oxygen in Basic Electric-Furnace Baths.** S. F. Urban and G. Derge. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2185:

Metals Technology, 1947, vol. 14, June). The oxygen contents of 30 basic electric-furnace heats during the refining period have been measured, using various sampling methods. The results indicate that (1) a minimum value of the oxygen content is reached after 40–80 min. under the reducing slag, this minimum value being dependent upon the carbon–oxygen equilibrium rather than on the time for which the metal is under the slag, and (2) the amount of sulphur held with a given slag is determined by its state of reduction rather than its basicity.—C. O.

**Slag Control in the Acid Electric Furnace.** H. H. Johnson, M. T. McDonough and D. L. Radford. (American Foundrymen's Association, 1947, Preprint No. 47-19). The results of a study of some of the characteristics of acid electric-furnace slags, together with some applications of these characteristics to serve as a guide for such furnace practice, are presented. Consideration is given to the correlation that might exist between such items as (*a*) slag viscosity and corresponding chemical composition, (*b*) slag composition and corresponding bath analysis and bath temperature, and (*c*) slag viscosity and composition in relation to the bath conditions that exist at several stages in the course of the melting cycle. —R. A. R.

**Slag Control by Routine Spectrographic Analysis.** J. T. Rozsa. (Metal Progress, 1947, vol. 51, Apr., pp. 593–597). An account is given of the use of spectrographic analysis in the control of slags at an American steel plant. The development of a satisfactory dephosphorization ratio and the accuracy of the method are discussed and a comparison is made with other techniques. —C. O.

**Record of Scientific Discovery in Iron and Steel.** Sir Charles Goodeve. (Board of Trade Journal, 1947, vol. 153, July 19, pp. 1213–1214). The history of individual and co-operative research in the British iron and steel industry culminating in the formation of the British Iron and Steel Research Association is briefly reviewed and the organization and programme of research of the Association are outlined.—M. A. V.

## FOUNDRY PRACTICE

**Making Steel Rolls.** B. W. Conroy. (United Effort, 1947, vol. 27, Apr., pp. 3–6). A brief illustrated description of the casting, machining, annealing, and finishing of steel rolls is given.—M. A. V.

**The Manufacture of Aircraft Components from Cast Steel.** R. Buquet. (Fonderie, 1946, Dec., pp. 397–415). This is an illustrated review dealing briefly with castings of copper–silicon steel in America, and Hadfield's retractable under-carriage for the "Typhoon." The second half of the paper gives a full account of visits made by a French investigating team to the Röchling Works at Völklingen and the Ruhrstahlwerke at Witten Annen.—R. A. H.

**Feeding of Metal Castings. Derivation of a General Equation for Gating Castings and Experimental Evidence in Support of Same.** A. F. Faber, jun., and D. T. Doll. (American Foundrymen's Association, 1947, Preprint No. 47-35).—R. A. R.

**Calculating Sizes of Gates and Risers.** N. Janco. (American Foundrymen's Association, 1947, Preprint No. 47-48).—R. A. R.

**Internal Risers for Steel Castings.** T. Shute. (Canadian Metals and Metallurgical Industries, 1947, vol. 10, Mar. pp. 24, 41, 44, 49–50). The advantages obtained by using internal risers for steel castings are discussed briefly.—C. O.

**Influence of Cast-In Chills on the Density and Strength of Bessemer Steel Castings.** E. Lanzendörfer. (Iron and Steel Institute, 1947, Translation Series, No. 314). This is an English translation of a paper which was published in Giesserei, 1932, vol. 19, May 13, pp. 181–186. (*See* Journ. I. and S.I., 1932, No. II, p. 515).—D. R. S.

**Core Sands and Binders.** O. J. Myers. (American Foundrymen's Association: Foundry, 1947, vol. 75, June, pp. 74–76, 192–200). A general account is given of the principles involved in the production of cores. —C. O.

**Aspects of German Foundry Practice.** (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1354: H.M. Stationery Office). A report is made of visits to fifteen German foundries and chemical factories to obtain information on the composition of melting fluxes, core binders, and parting powders.—C. O.

**Why Metal Penetrates Cores and Molds.** D. M. Bachelor. (Foundry, 1947, vol. 75, June, pp. 80–81, 235–238). An account is given of an experimental investigation of the penetration of molten metal into the core of a cast-iron crankshaft. The penetration is considered to be caused by the forcing apart of the sand grains by expansion and the deposition of carbon from hydrocarbon gases; the admixture of 1–2% of iron oxide with the core sand has solved the problem.—C. O.

**The Use of Cellulose Derivatives as Core Binders in German Foundries.** (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1219: H.M. Stationery Office). Tests made on small samples of cellulose derivatives made in Germany indicate that they have many desirable properties as core binders. —C. O.

**Some Moulding Problems and Their Solutions.** S. Jane. (Institute of British Foundrymen: Foundry Trade Journal, 1947, vol. 82, June 5, pp. 113–115, 118). The methods evolved to overcome specific problems in the founding of such articles as truck wheels and spare parts for tanks are outlined.—C. O.

**Production of Cast Crankshafts.** R. B. Templeton. (Institution of Automobile Engineers: Foundry Trade Journal, 1947, vol. 82, May 1, pp. 3–6; May 8, pp. 23–26, 32). The problems of design, application, production, and inspection of cast crankshafts are discussed and illustrated.—J. R.

**Making a 232-Ton Steel Casting.** (Foundry, 1947, vol. 75, May, pp. 78–79). A very brief account is given of the casting of a 232-ton steel forging-press frame at Pittsburgh.—C. O.

**A Survey of Precision Casting.** J. N. Read. (Metallurgia, 1947, vol. 35, Apr., pp. 275–278). An outline is given of the foundry technique of the "lost-wax" precision-casting process.—C. O.

**Making Practical Use of Precision Investment Casting.** A. Saunders. (Steel, 1947, vol. 120, Apr. 21, pp. 92–94, 117–120). An outline is given of the die-making, pattern-casting, heating, mould-making, casting, and cleaning operations in the production by the "lost-wax" process of small intricate ferrous and non-ferrous castings up to 5 lb. in weight.—R. A. R.

**Colloidal Graphite in the Metal Industry.** (Metallurgia, 1947, vol. 35, Apr., pp. 301–302). A brief account is given of the uses of colloidal graphite in such operations as die-casting, extrusion, stamping, and wire-drawing. —C. O.

**Metallurgical Topics—Continuous Casting.** H. Kästner. (Engineer, 1947, vol. 183, June 27, pp. 562–563). An abridged English translation is presented of a paper which appeared in Stahl und Eisen, 1947, vol. 67, Jan. 2, pp. 10–19 (*see* Journ. I. and S.I., 1947, vol. 156, June, p. 310).

**Temperature Distribution in Metal Moulds.** M. C. Udy and H. D. McIntire. (American Foundrymen's Association, 1947, Preprint No. 47-6). The substitution of thin-walled moulds for centrifugal castings and the use of air or water to cool these moulds are sometimes desirable. For design purposes in such a substitution, it is important to know the temperature distribution in moulds of various thicknesses under different conditions of cooling. In this investigation, the following variables were studied by measuring the temperature distribution in a test plate at intervals following the pouring of a casting on that plate : (1) Mould thickness ; (2) mould coating thickness ; (3) casting thickness ; (4) air or water for cooling ; (5) cooling-water flow ; (6) thermal conductivity of mould ; and (7) finned or plain plates. —R. A. R.

**Centrifugal Casting of Crank Cases—Middle Parts.** (Combined Intelligence Objectives Sub-Committee, 1947, File No. XXXIII–62 : H.M. Stationery Office).

**Segregation in Centrifugally Cast Gun Tubes.** (Combined Intelligence Objectives Sub-Committee, 1947, File No. XXXIII–61 : H.M. Stationery Office).

**Cleaning Room Practice.** M. P. Schemel. (American Foundryman, 1947, vol. 11, Feb., pp. 56–58). In giving an outline of the methods of cleaning and finishing castings used by the Symington-Gould Co., Depew, N.Y., the author emphasizes the economic importance of adequate inspection after each operation, *e.g.*, grinding, chipping, sand-blasting, etc.—C. O.

**Application of Hydro-Blast to Dressing and Sand Recovery.** W. Y. Buchanan. (Institute of British Foundrymen : Foundry Trade Journal, 1947, vol. 82, May 22, pp. 69–74 ; May 29, pp. 91–95). The reasons for the adoption of the Hydro-Blast system for cleaning castings at the foundry of Messrs. John Lang and Sons are given. The layout of the equipment is described, and the results obtained are discussed.—R. A. R.

**Evaluation of Core Knockout.** (American Foundrymen's Association, 1947, Preprint No. 47-43). This is a report by the American Foundrymen's Association Sub-Committee on Physical Properties of Iron Foundry Sands at Elevated Temperatures. Time studies were made, using a mechanical vibrating core-knock-out table, to determine the work involved in removing cores, and the results obtained were related to the properties of cores.—R. A. R.

**Automotive Foundries around Detroit.** (Foundry, 1947, vol. 75, Apr., pp. 94-105). Photographs of various operations in the foundries of the Ford, Packard, Dodge, Pontiac, and Wilson motor-car plants around Detroit are presented.—C. O.

**Duplexing Low Carbon Alloys.** E. S. Renshaw and T. Foley. (Iron Age, 1947, vol. 159, May 22, pp. 56–58). The plant and procedure at the Dagenham works of the Ford Motor Co., Ltd., for producing molten iron with 1·20–1·45% of carbon is described. This is a duplex process using a basic-lined cupola and an acid electric furnace. The equipment produced about 85 tons of hot metal per 9-hr. shift for the continuous casting of automobile parts.—R. A. R.

**How the Ford Rouge Foundry Handles Hot Metal for Continuous Pouring.** W. G. Patton. (Iron Age, 1947, vol. 159, Apr. 24, pp. 40–43). A description is given of the system by which molten metal is transferred from blast-furnace and cupola, through mixers and electric and air furnaces, to give a continuous supply to four lines of cylinder-block moulds at the River Rouge plant of the Ford Motor Company.—C. O.

**Pours Engine Castings in Dry Sand Moulds.** P. Dwyer. (Foundry, 1947, vol. 75, May, pp. 90–93, 112 ; June, pp. 88–91, 184–192). A detailed illustrated description is given of the layout, equipment, and moulding practice of the iron foundry of the Chicago Pneumatic Pool Company in Pennsylvania.—C. O.

**Kansas Manufacturers Build Modern Gray Iron Foundry.** (Foundry, 1947, vol. 75, June, pp. 92–93, 232–234). An illustrated description is given of a recently built mechanized grey-iron foundry at Pittsburg, Kansas, where castings up to 3 tons in weight can be produced at the rate of 25 tons/day.

**Steel Foundries.** (Combined Intelligence Objectives Sub-Committee, 1947, File No. XXXIII–518 : H.M. Stationery Office). This report on visits to German steel foundries is supplementary to C.I.O.S. Report XXXII–119.—R. A. R.

**Engineering Grey Iron.** (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1237 : H.M. Stationery Office). A detailed illustrated description is given of the equipment and techniques used at nine German grey-iron foundries.—C. O.

**Silicon Carbide Inoculation of Gray Cast Iron.** E. A. Loria, H. D. Shephard, and A. P. Thompson. (American Foundrymen's Association, 1947, Preprint No. 47-49). The normal chilling tendencies of unalloyed and alloyed cast iron can be controlled with silicon-carbide inoculation. In the particular iron considered in this investigation such treatment gives an improved chilled surface structure in which the primary carbides are much finer and uniformly dispersed. Of equal importance is the fact that silicon-carbide inoculation reduces the depth of chill and provides a shortened mottled zone in both plain and alloyed cast irons. The beneficial effect is clearly portrayed by photomicrographs which are representative of the types of structure obtained in the usual chilled iron as compared with the same iron containing the silicon-carbide addition. The structural refinement of the white-iron wear-resistant surface backed by a comparatively narrow zone of finely dispersed mottled iron caused a marked improvement in physical properties.—R. A. R.

**Importance of Radiography to Inspection.** E. L. LaGrelius. (American Foundrymen's Association, 1947, Preprint No. 47-16). The advantages of radiography for the inspection of castings are discussed and the need for agreement between the maker and the user on the testing conditions is emphasized.—R. A. R.

**Quality Control Methods.** J. W. Juppenlatz. (American Foundryman, 1947, vol. 11, Mar., pp. 50–56). The conditions which are essential for the production of castings of consistent quality are discussed. Non-destructive tests only contribute to the maintenance of quality in so far as they enable castings which do not meet the specifications because of defects or unsoundness to be rejected and permit the complete exploration of pilot castings. The quality of castings has its basis in design and the degree of control of the phases of the foundry operations.—C. O.

**Steel Casting Practice Modified by High-Voltage Inspection.** E. H. Grimm. (Steel, 1947, vol. 120, May 12, pp. 110–112, 136). The advantages of using a high-power X-ray apparatus for testing and controlling the quality of steel castings in the foundry are pointed out. —R. A. R.

**Graphite Phase in Gray Cast Iron.** R. W. Lindsay. (American Foundrymen's Association, 1947, Preprint No. 47-30). The paper reviews the factors affecting the development of the graphite structure in grey cast iron and the relationship of this graphite structure to the properties of cast iron.—R. A. R.



XUM

**Influence of Properties on Solidification of Metals.** V. Paschkis. (American Foundrymen's Association, 1947, Preprint No. 47-55, pp. 2–9). This is a report on further work done by the Heat Transfer Committee in which the solidification of castings is studied by the electrical analogy method (*see* Journ I. and S.I., 1946, No. 1, p. 61A). The present paper covers work on the influence of the specific heat, density, and thermal conductivity of the moulding sand, and of the heat of fusion, thermal conductivity, and volumetric specific heat (*i.e.*, density × specific heat) of the steel. The results indicated: (1) The pouring temperature and the solidification range have a marked influence on the beginning and end of solidification; (2) the specific heat determines the times for the beginning of freezing, but has little effect on the end of freezing; (3) the heat of fusion has a relatively small influence on the beginning of freezing and a great effect on the end of freezing; and (4) of the thermal properties, the conductivity has the least influence on solidification times.—R. A. R.

**Freezing Rate of White Cast Iron in Dry Sand Molds.** H. A. Schwartz. (American Foundrymen's Association, 1947, Preprint No. 47-55, pp. 14–15). The solidification of white cast iron in dry sand moulds was studied. The metal freezes somewhat rapidly during the first 3 min. The rate then decreases until about 5 min. after pouring when it suddenly increases. The dendrites in a slab 8 × 8 × 4 in. met in about 7 min., but it required over 45 min. for the interdendritic material at the centre to freeze completely.—R. A. R.

**Studies on Solidification of Castings—Approximate Equation for Steel Castings.** V. Paschkis. (American Foundrymen's Association, 1947, Preprint No. 47-55, pp. 22–23). This short paper summarizes the findings of the Heat Transfer Committee given in an earlier report by the present author (*see* Journ I. and S.I., 1946, No. 1, p. 61A) and offers a tentative general solution for problems relating to the rates of solidification for steel castings.—R. A. R.

**Some Aspects of the Solidification of Metals.** H. A. Stephens. (Australian Institute of Metals: Australasian Engineer, 1947, Feb. 7, pp. 74–93). The process of solidification of metals is traced from the formation of nuclei in the melt to the growth of crystal grains. Segregation and inverse segregation are discussed.—C. O.

**Foundry Costs and Cost Controls.** C. E. Westover. (American Foundrymen's Association, 1947, Preprint No. 47-42).—R. A. R.

**Foundry Dust Control Systems—Hoods and Piping.** E. A. Carsey. (American Foundryman, 1947, vol. 11, Mar., pp. 42, 46–47). The problem of the design of hoods and pipes for dust-control systems in foundries is discussed briefly.—C. O.

**Foundry Dust Control Systems—Maintenance.** K. M. Smith. (American Foundryman, 1947, vol. 11, Mar., pp. 43–45). The important points to be considered in the maintenance of hoods, pipes, fans, and collectors in foundry dust-control systems are discussed.—C. O.

**Present Problems in the Foundry Industry.** P. H. Wilson. (Institute of British Foundrymen: Engineering 1947, vol. 164, July 11, pp. 30–31). Problems regarding retaining existing labour in the foundries, the deployment of labour to the best advantage, and obtaining and training new employees are considered, and practical proposals for their solution are made.—R. A. R.

**Foundry Training Course for College Graduates.** (American Foundrymen's Association, 1947, Preprint No. 47-37). This is a report by the American Foundrymen's Association Subcommittee, Educational Division, on Training Graduate Engineers in Industry.—R. A. R.

**Foundry Practice for Engineering Students.** H. F. Scobie. (Journal of Engineering Education, 1947, vol. 37, May, pp. 689–694). The importance of increased co-operation between schools and industrial organizations, as recommended by the American Foundrymen's Association, is emphasized.—M. A. V.

## HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

**Heat Treating Aircraft Engine Parts at Pratt & Whitney Kansas City Plant.** (Industrial Heating, 1947, vol. 14, Feb., pp. 204–210; Mar., pp. 386–392; Apr., pp. 557–566). The heat-treatment furnaces used at a Kansas City aircraft-engine plant are described and illustrated. They include: (*a*) Pusher-type hardening and gas-carburizing furnaces; (*b*) electrically heated box-type tempering furnaces; (*c*) continuous brazing furnaces; and (*d*) pit-type carburizing and electric nitriding furnaces.—C. O.

**Ferrous and Non-Ferrous Metals Treated in Commercial Steel Treating Co. Plant.** (Industrial Heating, 1947, vol. 14, Apr., pp. 652–658; May, pp. 836–842). Descriptions are given of various types of heat-treating furnaces used at the works of the Commercial Steel Treating Co.—J. R.

**Bethlehem Expands Tool Steel Facilities.** R. J. Knerr and H. C. Bigge. (Iron Age, 1947, vol. 159, June 5, pp. 69–73). **Expanded Tool Steel Facilities.** R. J. Knerr and H. C. Bigge. (Steel, 1947, vol. 120, June 16, pp. 110–117, 132). Descriptions are given of the new equipment installed in the tool-steel department of the Bethlehem Steel Company during a modernization and expansion programme. The main improvements are in the heat-treatment, controlled-cooling, inspection, handling, and storage operations.—C. O.

**Foundries and Forge Shops Reduce Heat Treating Costs.** K. Rose. (Materials and Methods, 1947, vol. 25, Apr., pp. 100–102). An account is given of the improvements brought about in three Milwaukee, Michigan, foundries and forges by the replacement of old-fashioned equipment by modern high-production heat-treatment furnaces.—C. O.

**Heat-Treatment Furnaces—Some Recent Installations.** (Metallurgia, 1947, vol. 36, May, pp. 31–38). Present trends in the design of heat-treatment furnaces are illustrated by descriptions of typical recent installations for preheating, stress-relieving, carburizing, hardening and tempering, bright-annealing, and gas-malleablizing.—C. O.

**The Calculation of Nickel–Chromium Resistors in Heat-Treating Furnaces.** V. Paschkis. (Industrial Heating, 1947, vol. 14, May, pp. 756–760, 768). This is the continuation of a paper in which the design of nickel–chromium resistances for electric furnaces is discussed and the mathematical calculations involved are explained (*see* Journ. I. and S.I., 1947, vol. 156, July, p. 438).—J. R.

**Heat Treatment of Welded Constructions in Mild Steel.** (Transactions of the Institute of Welding, 1947, vol. 10, June, Supplement pp. 3–5). The recommendations made by the Committee FE.14 of the British Welding Research Association on the subject of the heat-treatment of mild steel structures fabricated by fusion welding are enumerated.—C. O.

**Decarburisation in Spring Wire—Its Cause and Control.** J. D. Joy and H. Morley. (Sheffield Spring Trade Technical Society: Wire Industry, 1947, vol. 14, May, pp. 262–273). The steps in the production of high-quality spring wire free from decarburization are described.—C. O.

**Heat Transfer from Submerged Surfaces to Boiling Liquids.** R. H. Baulk. (Monthly Bulletin of the British Coal Utilisation Research Association, 1947, vol. 11, June, pp. 185–192). This is a review of the available data on heat transfer from heated surfaces submerged in boiling liquids.—R. E.

**Modified Isothermal Treatments Minimize Distortion.** O. E. Brown. (Iron Age, 1947, vol. 159, Apr. 17, pp. 54–56). Heat-treatment cycles used for two carburized nickel-steel parts, a pinion and a gear with a hollow shaft, are outlined. The modified isothermal quench adopted results in very little distortion, without any sacrifice of surface hardness.—C. O.

**Austempered Cast Iron Serves as Cylinder Liners.** C. W. Ohly. (Materials and Methods, 1947, vol. 25, May, pp. 89–91). The austempering of cast-iron cylinder liners in immersion-heated salt baths is described. The process is said to result in a minimum of distortion, no decarburization, and uniform hardness.—C. O.

**Molten Salt Bath Practice and Salt Bath Design.** (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1281 : H.M. Stationery Office). A report is presented on present-day German practice in salt-bath heat-treatment and the construction of salt-bath furnaces ; the information was obtained in the course of a visit to Durferrit-Glüh und Härtetechnik, Frankfurt am Main.—R. A. R.

**Developments in the Applications of Controlled Atmospheres.** I. Jenkins. (Metallurgia, 1947, vol. 36, May, pp. 23–27). A summary is made of present practice in the use of controlled atmospheres for heat-treatments. Present applications of controlled atmospheres are in bright-annealing, patenting, carburizing, malleablizing, nitriding, gaseous deoxidation, descaling, and sintering metal-powder compacts. Possible future developments are suggested.—C. O.

**Induction-Hardening of Crankshafts.** G. W. Seulen. (Iron and Coal Trades Review, 1947, vol. 154, June 13, pp. 1073–1075). A loop-type inductor for hardening crankshaft journals and pins which was developed in Germany is described and illustrated.—C. O.

**A New Method of Coil Annealing.** H. H. Armstrong and F. F. Schlitt. (Iron and Steel Engineer, 1947, vol. 24, June, pp. 35–39). A description is given of a type of furnace for annealing sheet-metal coils in which the heat is transferred to or from the edges of the coils rather than through the laminations. The coils are stacked vertically inside a bell-type cover, provision being made for the circulation of gases between them by means of "compensating convectors." The furnace is heated by radiant tubes. It is claimed that much greater uniformity of heating is obtained and that large diameter coils can be annealed in a reasonable time. —C. O.

**Annealing Salt for 18–8.** K. Whitcomb. (Steel, 1947, vol. 120, June 16, pp. 86–87, 105–109). An account is given of tests made to determine the most suitable salt in which to anneal welded columbium- or titanium-stabilized stainless-steel sheets. Pure barium chloride and mixtures based on barium chloride proved unsatisfactory whilst pure sodium carbonate was found to be almost ideal—C.O.

**Lead Hardening.** B. Thomas. (Metallurgia, 1947, vol. 36, May, pp. 28–30). A short account is given of the technique of using lead baths for hardening small tools. Mention is made of the salt baths commonly used for quenching and tempering.—C. O.

**Some Experiments on Quenching Media.** F. W. Jones and W. I. Pumphrey. (Journal of the Iron and Steel Institute, 1947, vol. 156, May, pp. 37–54). In a search for a standard test for the comparison of the hardening properties of different quenching media, cooling rates were determined at the centre of a silver cylinder. An attempt was made to correlate the cooling rates thus obtained with the hardness found in quenched 1½-in. dia. cylinders of a high-carbon–chromium–molybdenum steel.

No simple method of correlation was apparent. Further quenching experiments were carried out with stainless-steel cylinders of various diameters, and qualitative agreement was obtained between predictions based on the cooling rates of the stainless-steel cylinders and hardnesses found experimentally in quenched cylinders of hardenable steels. The experiments with the silver cylinder showed that the value of the heat-transfer factor "$h$," as determined experimentally, varied considerably with temperature. For purposes of hardness correlation the effective value of "$h$" was found to depend also on specimen size.

**Tempering of Toolsteels.** M. Cohen. (Sauveur Memorial Lecture, American Society for Metals : Metal Progress, 1947, vol. 51, May, pp. 781–788 ; June pp. 962–968). After a brief review of the fundamentals of the cooling of steel, the various stages of tempering, as determined by the microscope, X-ray methods, and the magneto-dilatometer, are discussed.—C. O.

## LUBRICANTS AND LUBRICATION

**Analysis of Centralized Lubricating Systems.** J. P. Gravenstreter. (Iron and Steel Engineer, 1947, vol. 24, Mar., pp. 81–89, 97). Details of nine centralized lubrication systems are given and discussed.—J. R.

**Centralized Lubrication in Industry.** E. I. Pfaff. (Iron and Steel Engineer, 1947, vol. 24, Apr., pp. 77–81). The advantages of centralized lubrication are emphasized, and some industrial applications are described and illustrated.—J. R.

**Drawing Compounds Improve Press Potential.** S. Spring. (Machinist, 1947, vol. 91, June 14, pp. 205–216). The mechanism of the friction between metal surfaces in contact under high pressures is discussed, with reference to the functions of lubricating compounds. The properties desirable in a lubricant for drawing are that it should (1) prevent "welding" between the metal surfaces, (2) reduce friction, (3) be easily applied, (4) be easily removed, (5) be stable, and (6) be non-corrosive. An outline is given of chemical and physical tests of lubricants, and recommendations are made for the compositions of lubricants suitable for specific ferrous and non-ferrous metals.—C. O.

**Composition, Control and Selection of Coolants for Working Metals.** E. L. H. Bastian. (Steel, 1947, vol. 120, May 19, pp. 82–83, 117–124 ; May 26, pp. 94–95, 107–112). The preparation, properties, and control of aqueous solutions and emulsions as cooling and lubricating agents for machining, rolling, drawing, and grinding are discussed, and the factors influencing the choice of cooling agents for particular operations are outlined.—R. A. R.

**Evaluation of High Temperature Greases.** R. C. Adams and S. M. Collegeman. (Journal of the American Society of Naval Engineers, 1947, vol. 59, Feb., pp. 22–32). An account is given of the development by the United States Navy of methods and equipment for the testing of high-temperature greases—R. E.

**Latest Hypoid Lubricants.** C. F. Prutton. (Steel, 1947, vol. 120, Mar. 31, pp. 84–85, 106–109). The effect of addition agents containing chlorine on the lubricating properties of oils for hypoid gears is discussed. The formation of minute quantities of ferrous chloride on the high points of the gear surfaces is beneficial because it prevents metal to metal contact.—R. A. R.



XUM

**Geometrical and Metallurgical Changes in Steel Surfaces under Conditions of Boundary Lubrication.** B. W. Sakmann. (Journal of Applied Mechanics, 1947, vol. 14, Mar., pp. A-43–A-52). The changes taking place in steel and cast-iron surfaces during running-in tests under similar conditions of lubrication to those encountered in industrial practice have been investigated. The contour of the surfaces was altered in all cases, initially rough surfaces becoming flattened and initially smooth surfaces becoming roughened. In some of the chromium-steel and cast-iron specimens metallurgical changes were observed and studied by etching and X-ray analysis. The temperatures reached during the tests have been calculated from thermal conductivities, and a tentative explanation of the origin of the transformations is offered.—C. O.

## WELDING AND FLAME-CUTTING

**Some Metallurgical Aspects of Welding.** J. Kelly. (Australian Welding Institute: Australasian Engineer, 1947, Feb. 7, pp. 66–73). A general account is given of the metallurgy of welding steel by fusion processes. —C. O.

**S-Curves Point the Way for Successful Welding of Any High-Carbon or Alloy Steel.** L. Berner. (Welding Journal, 1947, vol. 26, Feb., pp. 110–113). After a simple explanation of the construction of S-curves, examples are given to show how they can be applied in welding, to avoid the hardening which leads to cracking and residual stresses.—C. O.

**Building Code Requirements for Welding Structural Steel.** S. A. Greenberg. (Welding Journal, 1947, vol. 26, Mar., pp. 219–222). A summary is given of the replies to a questionnaire sent by the American Welding Society to 205 American city authorities. The questionnaire dealt with the standards enforced by municipal and other governing bodies for welded structural steelwork in buildings.—C. O.

**The Application of Electric Arc Welding to Ship Construction.** (Admiralty Memorandum M.2, 1946: H.M. Stationery Office). The object of this Memorandum is to set out, on the basis of the data made available to the Admiralty Ship Welding Committee, factors to which special consideration should be given in the welding of ships' structures.—R. A. R.

**The Examination of Arc Welds in the Shipyard.** (Admiralty Memorandum M.4, 1946: H.M. Stationery Office). This Memorandum contains recommendations by the Admiralty Ship Welding Committee for the guidance of shipbuilders, designers, inspectors, and foremen engaged in the fabrication of ships' structures by welding.—R. A. R.

**Welded Ship Fractures.** E. C. Kreutzberg. (Steel, 1947, vol. 120, June 16, pp. 120–122). The findings of the board investigating the wartime failures in American welded merchant ships are summarized.—C. O.

**Welding as Applied to Military Bridging.** R. A. Foulkes. (Transactions of the Institute of Welding, 1947, vol. 10, June, pp. 78–89). The part played by welding in solving problems connected with the design of military bridging equipment is discussed. The influence of welding on the design of the Bailey bridge, the Bailey pontoon, and the Bailey suspension bridge is illustrated. —C. O.

**Welding Power Piping with Chromium–Molybdenum Electrodes.** O. T. Barnett. (Steel, 1947, vol. 120, May 26, pp. 88–90, 125–130). Data are given on the composition and properties of the electrodes, containing 0·5–3·0% of chromium and 0·5–1·0% of molybdenum, which are used for welding low-alloy chromium–molybdenum steel high-pressure steam pipes.—C. O.

**The Welding of High-Temperature, High-Pressure Steel Valves.** V. T. Malcolm and S. Low. (Welding Journal, 1947, vol. 26, Feb., pp. 101–110). The materials and techniques necessary for the welding of steel valves for controlling steam at pressures of up to 1400 lb./sq. in. and temperatures up to 1000° F. are discussed in detail. —C. O.

**A New Method for the Welding of Rail Joints.** F. Wörtmann. (Journal of the Iron and Steel Institute, 1947, vol. 156, June, pp. 261–270). After a brief review of present day arc-welding practice in Switzerland, a method developed by the Société Anonyme des Ateliers de Sécheron for the welding of rail joints is described. This method does not necessitate any interruption of traffic, nor are special tools required, and the joints produced possess a high fatigue strength. Results obtained on an experimental track of the Schweizerische Bundesbahnen are reported.

**Submerged Melt Welding in Pressure Vessel Fabrication.** N. G. Schreiner. (Welding Journal, 1947, vol. 26, May, pp. 400–407; Steel Processing, 1947, vol. 33, Mar., pp. 169–174, 180). The principles of the Unionmelt welding process are explained, and the techniques used in applying the process to the fabrication of steel pressure vessels are illustrated.—C. O.

**Depositing Overlaid Surfaces by the Submerged Melt Welding Process.** L. C. Bradburn, J. M. Keir, and J. E. Taylerson. (Welding Journal, 1947, vol. 26, Apr., pp. 297–300). The welding of alloy steel layers on to plain carbon steel by the Unionmelt welding process is described.—R. A. R.

**Submerged Melt Welding of Corrosion-Resistant Metals.** R. J. Anderson and H. J. Roberts. (Welding Journal, 1947, vol. 26, Apr., pp. 338–342). The welding of stainless steel, Everdur, Monel metal, and other alloys by the Unionmelt method is described.—R. A. R.

**Flexible Multi-Transformer Welder Boosts Steel Drawer Output.** (Iron Age, 1947, vol. 159, June 5, p. 79). A very short description is given of an automatic multi-transformer machine for welding steel drawers at the rate of 300/hr.—C. O.

**Inert-Gas-Shielded Arc Welding for Difficult-to-Weld Materials.** H. R. Clauser. (Materials and Methods, 1947, vol. 25, Apr., pp. 86–90). A general account is given of the characteristics, costs, and techniques of Heliarc welding of materials such as stainless steel, magnesium, aluminium, Hastelloy alloys, and Everdur. —C. O.

**How Atomic-Hydrogen Arc Welding Aids Production.** R. F. Wyer. (Steel Processing, 1947, vol. 33, May, pp. 287–289, 307). The advantages of atomic hydrogen welding are enumerated and equipment for the manual and machine operation of the process is described and illustrated.—R. A. R.

**Atomic Hydrogen Welding of Stainless Sheet.** G. Richardson. (Iron Age, 1947, vol. 159, May 8, pp. 72–74). The technique for atomic hydrogen welding stainless steel parts for jet engines is described. Experiments on substitutes for hydrogen shewed that nitrogen and town's gas were unsatisfactory, but helium would be used if the cost were not too great.—R. A. R.

**The Welding of Stainless Steel for Jet Propulsion.** E. J. DeWitt and F. J. Lammers. (Welding Journal, 1947, vol. 26, Apr., pp. 320–323). The training of operators and the development of techniques for welding stainless steel in the assembly of jet-engine parts are described.—R. A. R.

**"Musts" in Silver Brazing Stainless.** A. W. Swift. (Steel, 1947, vol. 120, Apr. 28, pp. 98–99, 132). The technique for silver-brazing stainless steel is described.— R. A. R.

**How Silver Brazing May Simplify Casting Design.** S. D. Heron. (Steel, 1947, vol. 120, Apr. 17, pp. 90–91, 120–122). Examples are given to illustrate the use of silver and bronze welding in building up complicated parts from two or more simple iron castings.—C. O.

**Effects of Flux in Welding Stainless Steel.** G. Richardson. (Iron Age, 1947, vol. 159, May 1, pp. 42–46). In the atomic-hydrogen welding of stainless steel nozzle boxes for superchargers the under side of the weld was protected from oxidation by a flux. In some cases cracks developed and in others a eutectic constituent caused brittleness. An investigation of welds made with different fluxes is described. Fluxes containing borates were very liable to form bad welds. Protection of the under side of the weld with hydrogen is desirable.

**An Investigation of the Influence of Hydrogen on the Ductility of Arc Welds in Mild Steels.** A. E. Flanigan. (Welding Journal, 1947, vol. 26, Apr., pp. 193-s–214-s). An account is given of an investigation of the effect of hydrogen in the operation of welding 0·2% carbon steel. The introduction of hydrogen into hydrogen-free welds by pickling produced embrittlement even when the amount added was less that that present after normal welding. Excluding the tests on pickled welds, the remaining evidence failed to establish the relation between the hydrogen content and the ductility. Post-heating at above 850° F. eliminated all hydrogen in a short time and greatly increased the ductility, whilst treatments at 250° and 650° F. caused a considerable increase in the ductility.—R. A. R.

**Classification of Arc Welding Electrodes.** (Transactions of the Institute of Welding, 1947, vol. 10, Apr., pp. 45–50). This is a report from the Joint Committee set up by the Institute of Welding and the Arc-Welding Electrodes Section, Technical Committee of the British Electrical and Allied Manufacturers' Association (B.E.A.M.A.) in 1945 to consider and report upon a scheme for the classification of arc-welding electrodes.

## MACHINING AND MACHINABILITY

**Machinability and Structure of Ferrous Materials.** C. Sykes. (Conference on Machinability: Proceedings of the Institution of Mechanical Engineers, 1946, vol. 155, pp. 235–236). A short account is given of the effect of structure and mechanical properties on the machinability of ferrous materials.—C. O.

**Testing Methods Using Pendulum Machines.** A. S. Kenneford. (Conference on Machinability : Proceedings of the Institution of Mechanical Engineers, 1946, vol. 155, pp. 241–243). Descriptions are given of the Oxford-Airey and the Leyensetter double-pendulum machines for the assessment of machinability, and the results of tests at the Armament Research Department with a machine of the Oxford-Airey type are presented.—C. O.

**Notes on Machinability Testing Apparatus and Tests Carried Out at the Naval Ordnance Inspection Department, Sheffield, Including a Development of the Drill Test.** D. G. W. Curry. (Conference on Machinability : Proceedings of the Institution of Mechanical Engineers, 1946, vol. 155, pp. 244–246). Descriptions are given of apparatus developed for the routine testing of the machinability of shell steels. Data obtained during trials with a drilling test are presented.—C. O.

**Standardization of Tools for Machinability Tests.** C. H. Booth. (Conference on Machinability : Proceedings of the Institution of Mechanical Engineers, 1946, vol. 155, pp. 246–247). The characteristics of machine tools which should be standardized in order to obtain comparable results in machinability tests are discussed.—C. O.

**A Tentative Method of Assessment of Machinability.** C. W. George. (Conference on Machinability : Proceedings of the Institution of Mechanical Engineers, 1946, vol. 155, pp. 248–255). A scheme proposed by a panel set up by the Ministry of Aircraft Production to enable a broad indication of the machining properties of new materials to be obtained is explained.—C. O.

**Tool Wear as a Measure of Machinability.** C. Eatough. (Conference on Machinability : Institution of Mechanical Engineers, 1946, vol. 155, pp. 255–257). A description is given of investigations of the wear of tools, tipped with tungsten titanium carbide, during machining.—C. O.

**Tool Materials.** J. E. Attwood. (Conference on Machinability : Proceedings of the Institution of Mechanical Engineers, 1946, vol. 155, pp. 260–261). The conditions of service and performance which govern the choice of materials for cutting tools are discussed.—C. O.

**The Broachability of Materials.** H. Gotberg. (Materials and Methods, 1947, vol. 25, Apr., pp. 103–107). The principles of broach design are briefly explained and a summary is made of the broaching characteristics of the common ferrous and non-ferrous metals.—C. O.

**German War Time Work on Machinability, Economy High Speed Steels, Lead-Bearing Steels.** (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 519 : H.M. Stationery Office). The work done in Germany during the war on machinability and allied subjects is reviewed. The report is in three parts, dealing with : (1) Researches on machinability tests ; (2) the development and performance of low-alloy high-speed tool steels ; and (3) investigations on lead-bearing steels.—C. O.

**Modern Band Sawing Practice.** H. J. Chamberland. (Iron Age, 1947, vol. 159, Apr. 17, pp. 64–66). Recent developments in the band-sawing of ferrous and non-ferrous metals and plastics are reviewed. The modern tendency is to employ saw speeds as high as 5000 ft./min. In a newer development, *i.e.*, friction sawing, band speeds of up to 15,000 ft./min. are used for cutting steel.—C. O.

**Industrial Diamonds Used by Diamond Tool Manufacturers in Japan.** (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./781 : H.M. Stationery Office).

**Results of an Investigation of the Removal of Metals by the Process of Grinding.** R. E. McKee, R. S. Moore, and O. W. Boston. (Transactions of the American Society of Mechanical Engineers, 1947, vol. 69, Feb., pp. 125–129). The results are presented of an investigation to determine the influence of grinding wheels and grinding compounds on the process of grinding steel cylinders.

**Hardness Distribution in Chips and Machined Surfaces.** N. Zlatin and M. E. Merchant. (American Society of Mechanical Engineers : Iron Age, 1947, vol. 159, May 22, pp. 69–75). A report is presented of an investigation of the distribution of hardness in steel chips and machined surfaces caused by the cutting tool.—R. A. R.

**Influence on Tool Life and Powers of Nose Radius, Chamfer, and Peripheral-Cutting-Edge Angle when Face-Milling a 40,000-Psi Cast Iron.** O. W. Boston and W. W. Gilbert. (Transactions of the American Society of Mechanical Engineers, 1947, vol. 69, Feb., pp. 117–124). In the investigation described, tools with a nose-radius of $\frac{1}{4}$ in. gave the best performance at cutting speeds below 800 ft./min. The longest tool life was obtained with tips having the longest chamfer, and the tools with higher peripheral-cutting-edge angle required more rigidity of the work and larger relief angles than those tools with smaller angles.—C.O.

**The Hardened and Tempered Microstructure of High-Speed Tool Steel as a Factor in Tool Performance.** W. H. Wooding. (Transactions of the American Society of Mechanical Engineers, 1947, vol. 69, May, pp. 280–306). Tables and diagrams are presented which show the results of studies of the cause of variations in the life of high-speed-steel tools during rough-turning tests.—C. O.

**Surface Finish of Steel in Face-Milling.** A. O. Schmidt. (Transactions of the American Society of Mechanical Engineers, 1947, vol. 69, May, pp. 325–327). Exhaustive tests have shown that the radial rake angle has relatively little effect upon surface finish in face-milling operations. Surface finish is determined by cutting speed and feed per tooth, *i.e.*, the higher the speed and finer the feed, the better the finish ; at too high speeds or too fine feeds tool wear becomes extreme.—C. O.

**Methods of Increasing Fatigue Strength of Gear Teeth.** (Machinery, 1947, vol. 70, June 5, pp. 601–602). A lapping process for removing surface-finish lines at right angles to the direction of rotation of gear teeth, and a technique of "root relieving" gear wheels by cutting away and shot-peening are briefly described.—C. O.

**Determining Surface Roughness.** W. Mikelson. (Mechanical Engineering, 1947, vol. 69, May, pp. 391–393). A procedure for providing standards of surface roughness for the machine shop is described. It consists of comparing the product by sight and feel with a set of ten specimens of different grades of roughness. An electroplating method of producing many sets of specimens from a master set is described.—R. A. R.

**Ball and Roller Bearings.** (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1242 : H.M. Stationery Office). Detailed descriptions are given of the operations in the manufacture of components of the principal type of ball and roller bearings at five German factories.—C. O.

**The Present Position of the Standardization of Screw Threads by the Inch and Metric Measuring Systems 1945/1946.** F. Wild. (Schweizer Archiv, 1946, vol. 12, Sept., pp. 265–278).—R. A. R.

**Manufacture, Selection and Use of Files.** L. E. Browne. (Steel, 1947, vol. 120, May 12, pp. 103–105, 132–136 ; May 19, pp. 91–92, 130–132 ; May 26, pp. 96–98, 132–136).

**Vibration Testing and Product Acceptability.** H. Johnston. (Iron Age, 1947, vol. 159, May 15, pp. 58–61). In order to improve the quality of machined products, vibration of the machine tools must be reduced to a minimum. An electronic vibration-testing machine and meter is described and illustrated.—R. A. R.

## POWDER METALLURGY

**Modern Powder Metallurgy.** H. W. Greenwood. (Engineering, 1947, vol. 163, June 13, p. 492). The author reviews achievements in the field of powder metallurgy and shows that a state of transition between a period of empiricism and a period marked by the marshalling of empirical knowledge has now been reached. The field for future investigations is examined.—R. A. R.

**A Challenge : Powder Metallurgy.** A. J. Langhammer. (Modern Metals, 1947, vol. 3, June, p. 13). This is a brief discussion, without technical details, of the production of "oilite" bearings from powdered metals, including iron and stainless steel.—M. A. V.

**Economics of Iron Powder Manufacture.** J. F. Sachse. (Iron Age, 1947, vol. 159, May 22, pp. 62–63). Data on the commercial aspects of producing iron powders in the United States are presented and discussed.—R. A. R.

**Powder Metallurgy—Process or Product ?** E. S. Patch. (Iron Age, 1947, vol. 159, May 22, pp. 64–66). The author considers that more energy should be devoted to making powder metallurgy a recognized production process and that it could, with profit, become accepted as a department in a factory in the same way as, for example, a heat-treatment department.—R. A. R.

**New Developments in Powder Metallurgy.** J. C. Comstock and J. D. Shaw. (Iron Age, 1947, vol. 159, May 22, pp. 67–68). A great extension to the field of powder-metallurgy products is envisaged from the increased use of alloy powders and hot-pressing.—R. A. R.

**Sintered Iron and Steel for Structural Parts.** R. Kieffer, F. Benesovsky, and H. J. Bartels. (Powder Metallurgy Bulletin, 1947, vol. 2, May, pp. 54–69). The various applications of components made of sintered iron, steel, and iron alloys are reviewed. The advantages of sintering over other methods of fabrication for particular purposes are summarized, and the various processes involved in making sintered components from powder compacts are described. Data on the engineering properties of sintered iron and steel parts as compared with those of corresponding standard steels are presented in tabular form, and the effects of heat-treatment on sintered steel are described. It is noted that, with a sintered steel of 0·8% carbon made from soft iron powder and graphite powder, it is possible to obtain a Rockwell C hardness of 56–59. A bibliography of 40 references is appended.—M. A. V.

**Proceedings, Second Annual Spring Meeting, Metal Powder Association.** (Metal Powder Association, 1946, Symposium). The Second Annual Spring Meeting of the Metal Powder Association was held in New York on June 13, 1946. Eight papers on powder metallurgy were presented, abstracts of which are given below.—R. A. R.

**Use of Graphite in Iron Powder Compacts.** E. S. Glauch. (*Ibid.*, pp. 2–12). The influence of type of graphite on the physical properties of steels made from mixed iron–graphite powder mixtures has been determined. Natural flake and crystalline graphites gave the best results. A synthetic graphite was slightly inferior, and amorphous graphite worst.—C. O.

**Furnace Atmospheres for Sintering.** H. M. Webber and A. G. Hotchkiss. (*Ibid*, pp. 13–39 : Industrial Heating, 1947, vol. 14, May, pp. 742–754). The methods of producing, purifying, and controlling atmospheres of hydrogen, cracked ammonia, and partially burned town gas for use in sintering furnaces are reviewed.—C. O.

**Sintered High Density Tungsten and Tungsten Alloys.** J. Kurtz. (*Ibid.*, pp. 40–52). The techniques used by the Callite Tungsten Corp., Union City, N.J., for sintering compacts of 85–90% tungsten alloy, pure tungsten, and pure molybdenum powders are briefly described. The influence of particle size on the microstructure and density is illustrated by photomicrographs.—C. O.

**Fundamental Facts about Iron Powder Costs.** B. T. du Pont. (*Ibid.*, pp. 54–59). The factors which determine the cost of iron powders are analysed. Manufacturing costs are mainly influenced by the quantity of powder produced and the quality required. It is shown that even for a company producing 1,500,000 lb. per year (the total American production is only 4,000,000 lb. per year) the cost of plant, equipment, labour, and research cannot be less than 11–12 cents/lb. ; but if production could be increased to 6,000,000 lb. per year, this overhead cost could be reduced to 2·75 cents/lb.—C. O.

**Testing Methods in Use in Determining the Properties of Iron Powders.** J. E. Drapeau, jun. (*Ibid.*, pp. 60–64). The author comments briefly on the standardization of methods of testing iron powder.—C. O.

**Some Relationships between Properties of Iron Powders and Properties of Parts Made from Them.** F. V. Lenel. (*Ibid.*, pp. 65–72). The effects of compressibility and the rate of absorption of carbon by iron on the properties of iron and iron–carbon powder compacts, and the hardenability of steels made by powder metallurgy are discussed.—C. O.

**Physical Properties of Parts Made from Iron Powders.** C. G. Goetzel. (*Ibid.*, pp. 73–79). A summary is made of the various methods, such as hot-pressing, coining, and alloying, which have been used to reduce the porosity, and thus improve the physical properties, of iron-powder products.—C. O.

**An Editor's View of Ferrous Powder.** F. P. Peters. (*Ibid.*, pp. 80–86). The answers given by the most important United States producers and fabricators of metal powders to a confidential enquiry concerning the quality and price of metal powders are summarized. —C. O.

**Iron–Graphite Powder Compacts.** A. Squire. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2164 : Metals Technology, 1947, vol. 14, Apr.). An account is given of an investigation of the effect on the density and tensile properties of iron–carbon powder compacts of (1) compacting pressure, (2) sintering time, (3) particle size, (4) sintering temperature, and (5) type of iron powder. It was found that the strengths of 99/1 iron–graphite compacts increased with decreasing graphite particle size. Increase in sintering time at temperatures between 1000° and 1050° C. led to increases in tensile strength for all particle sizes. An increase in compacting pressure raised the entire curve of tensile strength against compacting pressure. Graphite particle size had little influence on the microstructure of sintered compacts.—C. O.

**Density Relationships of Iron-Powder Compacts.** A. Squire. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2165 : Metals Technology, 1947, vol. 14, Apr.). An account is given of an investigation of the effects on the mechanical properties of iron-powder compacts of variations in density from 4·8 to 7·5 g./c.c. For six different types of iron powder the tensile strength and hardness were found to be roughly proportional to the density. The elongation and impact resistance were exponential functions of density. Experiments were also made to determine the effect of die configuration and frictional forces on the density of compacts.—C. O.

**Sintered Permanent Magnets.** S. J. Garvin. (Engineering, 1947, vol. 163, May 30, pp. 445–446 ; June 6, pp. 465–467). The development of permanent-magnet alloys is reviewed and a detailed account is given of the manufacture of sintered Alnico magnets by powder metallurgy. To prevent oxidation of the pressings these are packed in heat-resisting alloy or refractory boxes which also contain a powder the function of which is to absorb the traces of oxygen in the furnace atmosphere. Data on the magnetic properties and the dimensional tolerances which can be maintained in manufacture are presented.—R. A. R.

**The Production of Powdered Iron, and Sintered Iron Driving Bands in Germany.** (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1323 : H.M. Stationery Office). This report contains the results of investigations on the production and use of sintered iron and steel in Germany, with special reference to the manufacture of projectile driving bands and the research work involved in the development of the processes for making atomized powder.—C. O.

**Iron Powders and Sintered Components.** (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1223 : H.M. Stationery Office). In the first part of this report a general survey is made of German methods of producing iron powders and sintered products, such as driving bands and fuse bodies, and the results of research work on powder metallurgy at the Kaiser-Wilhelm-Institut für Eisenforschung are summarized. The second part of the report contains details of the practice at individual works producing iron powders and components.—C. O.

## PROPERTIES AND TESTS

**Engineering Significance of Metals Testing.** B. D. Mills, jun. (Iron Age, 1947, vol. 160, Aug. 7, pp. 78–83). The author discusses the common types of mechanical testing from the viewpoint of their correlation with engineering design.—C. O.

**Influence of Structure and Composition of Metallic Alloys on their Elastic Properties.** L. Guillet. (Génie Civil, 1947, vol. 124, Feb. 1, pp. 45–50). The modulus of elasticity and the internal friction of metallic alloys are discussed. A short bibliography is appended.—R. F. F.

**Criteria for the Resistance of Materials.** R. Vallette. (Génie Civil, 1947, vol. 124, Feb. 15, pp. 78–79). The author critically discusses the question of criteria for the resistance of matter to stress, and in particular certain deficiencies in Mohr's theory.—R. F. F.

**The Study of Single-Crystal Specimens Contributes to the Knowledge of Mechanical Properties of Metals.** L. Guillet, jun. (Mémoires de la Société des Ingénieurs Civils de France, 1944, vol. 97, Jan.–Dec., pp. 20–32). This is a summary of the work of various investigators. —J. C. R.

**Influence of the Structure and Composition of Metallic Alloys on their Elastic Properties.** L. Guillet. (Mémoires de la Société des Ingénieurs Civils de France, 1946, vol. 99, June–Aug., pp. 196–209). The author has investigated the elastic deformation of metals and their alloys and draws the following conclusions : (a) The modulus of elasticity is an atomic property which is only slightly sensitive to variation in chemical composition and structure ; and (b) damping capacity or internal friction is very sensitive to variations in chemical composition and structure.—J. C. R.

**Contribution to the Study of the Influence of Heat-Treatment on the Elastic Limit of Tensile Steels.** J. M. Vialle. (Mémoires de la Société des Ingénieurs Civils de France, 1945, vol. 98, Jan.–Mar., pp. 100–134). Results are presented of tests carried out on various steels to discover the effect of different methods of heat-treatment on their elastic properties.—J. C. R.

**A Study of the Tension Test.** E. R. Parker, H. E. Davis, and A. E. Flanigan. (Proceedings of the American Society for Testing Materials, 1946, vol. 46, pp. 1159–1174). Experiments carried out to determine the nature of fractures in mild-steel cylindrical bars broken in tension at various temperatures are described. Microscopical examination of fractured ferrite crystals, using an etch-pit technique, showed that the specimens tested at 70° F., failed entirely by shear, those tested at liquid-air temperature failed entirely by cleavage, and those at intermediate temperatures exhibited both types of fracture. Shear-type fractures were observed to originate in the central portion of test-pieces at normal temperatures, and an approximate analysis of the state of stress just before fracture indicates that the shear

stress is greatest at this part of the neck. Two appendices to the paper contain methods for the determination of residual stresses at the necked section of a bar and the calculation of unloading stresses.—C. O.

**Tensile Testing—New Tangye 25-Ton Universal Hydraulic Machine.** (Iron and Steel, 1947, vol. 20, July, pp. 362). The characteristics of a new 25-ton tensile and compression testing machine are briefly indicated—C. O.

**Precision Determination of Stress-Strain Curves in the Plastic Range.** J. R. Low, jun., and F. Garofalo. (Proceedings of the Society for Experimental Stress Analysis, 1947, vol 4, No. 2, pp. 16–24). A method for the determination of simple tension stress-strain curves in the plastic range, using a ring dynamometer to measure loads and a straight-beam "clip gauge" with a sensitivity of 0·0001 in./in. to measure strains, is described. The validity of the expression $\sigma = K\delta^n$ for the stress-strain relationship was verified for a variety of steels and two aluminium alloys. Only austenitic stainless steel failed to conform to this general law.—C. O.

**Reluctance Gages for Telemetering Strain Data.** W. H. Pickering. (Proceedings of the Society for Experimental Stress Analysis, 1947, vol. 4, No. 2, pp. 74–77). The design of reactance gauges for the transmission of strain measurements over long distances (*e.g.*, by wireless) is discussed.—C. O.

**The Evaluation of Mechanical Properties of High-Tensile Steel for Welded Structures.** O. Graf. (Zeitschrift des Vereines deutscher Ingenieure, 1943, vol. 87, July 10, p. 422; Welding Journal, 1947, vol. 26, June, pp. 367-s–368-s). The results of experiments to determine the relationship between permissible working stress and yield point, the effect of residual stress on load-carrying capacity, and the suitability for welding of various high-tensile steels are summarized.—C. O.

**Evaluation of Various Methods of Rotor-Blade Analysis by Means of a Structural Model.** R. Mayne. (Proceedings of the Society for Experimental Stress Analysis, 1947, vol. 4, No. 2, pp. 62–73). Tests made on a structural model of a rotor blade under static loading to determine the most suitable method of propeller analysis for rotor blades are described.—C. O.

**Effect of Welding on Ductility and Notch Sensitivity of Some Ship Steels.** R. D. Stout, L. J. McGeady, C. P. Sun, J. F. Libsch, and G. E. Doan. (Welding Journal, 1947, vol. 26, June, pp. 335-s—357-s). In Part I of this paper a report is made of studies of the effect of the base metal, electrode type, welding technique, and other variables on the notch sensitivity and ductility (as measured by the longitudinal notch bend test) of welded carbon and high-tensile alloy ship steels. Part II is concerned with investigations of the influence of hydrogen, cooling rates, and metallurgical structure on the notch brittleness and ductility of welded plates, and Part III deals with experiments with plates heat-treated and welded in hydrogen-bearing and hydrogen-free atmospheres, Charpy V-notch bars being used to measure ductility.—C. O.

**Photoelastic Stress Analysis.** (Mechanical World, 1947, vol. 121, May 16, pp. 473–475). **The Polariscope.** (Automobile Engineer, 1947, vol. 37, June, pp. 231–232). **Stress Distribution.** (Iron and Steel, 1947, vol. 20, June, pp. 311–313). **Using the Polariscope for Stress Analysis.** (Steam Engineer, 1947, vol. 16, June, pp. 340–343). **The Use of the Polariscope in Stress Analysis.** (Machinery, 1947, vol. 70, June 19, pp. 651–653). **Polarized Light for Stress Analysis.** (British Steelmaker, 1947, vol. 13, July, pp. 359–361). **Using the Polariscope for Stress Analysis.** (Steam Engineer, 1947, vol. 16, July, pp. 340–343). A brief outline is given of the use of photo-elastic analysis for the determination of the stresses in engineering components.—C. O.

**The Equilateral Electric Strain Gage Rosette.** G. Brewer. (Metal Progress, 1947, vol. 51, May, pp. 758–763). The theory of the equilateral electric-strain-gauge rosette is simply explained, with illustrated examples of its application in determining stresses in structures such as cylinder walls, aeroplane wings, and curved panels.—C. O.

**Proof Loading—An Essential Non-Destructive Test.** J. C. New. (Industrial Radiography, 1947, vol. 5, Spring Issue, pp. 37–40). The advantages of "proof loading" as a 100% inspection test of fabricated parts are explained. ("Proof loading" is the application of a load to a structure in such a manner that the resulting stresses are equal to or greater than the stresses to which the structure is subjected in service). The determination of the stresses in a torpedo suspension band, by strain-sensitive brittle-lacquer coatings and by electric strain gauges, during the development of a routine proof-loading test, is described.—C. O.

**Brittle Fracture in Mild Steel Plates.** (British Iron and Steel Research Association, Proceedings of a Conference at the Engineering Laboratory, Cambridge University, Oct., 1945). A conference was held at Cambridge on Oct. 26, 1945, under the auspices of the British Iron and Steel Research Association, the Admiralty Ship-Welding Sub-Committee, and the British Welding Research Association, to discuss the problem of the failure of mild-steel plates by brittle fracture. Abstracts of the eight papers which were read follow.

**The Problem of Brittle Fractures in Ship Structures.** J. F. Baker. (*Ibid.*, pp. 7–21). An analysis is made of the possible causes of brittle fractures in welded mild-steel plates in ships. The possible effects of welding are divided into two groups, primary (*viz.*, faults and weaknesses in the welds, locked-up or residual stresses, and abrupt changes of cross-section) and secondary, those due to the almost perfect continuity of the structure (*viz.*, self-straining, temperature stresses, and fatigue), and each is discussed in turn. A résumé of the present state of knowledge of the causes of low ductility in mild steel is contained in an appendix, together with 89 references to the literature.—C. O.

**Brittle Fracture of Mild Steel Plates.** C. F. Tipper. (*Ibid.*, pp. 23–50). Experiments are described which were made to reproduce in the laboratory the types of fracture found in welded steel ship plates, and to investigate the conditions which favour the occurrence of such fractures. It is shown that certain steels can be fractured with relatively little plastic extension when pulled in tension if a notch (in the widest sense of the term) is present. The breaking stress was in no case less than the yield stress obtained in a normal test. The type of fracture was found to be very sensitive to temperature. A report on the structure of the steels used in the experiments is contained in Part II of the paper.—C. O.

**Brittleness in Ship Steel—Practical Aspects of the Problem.** J. L. Adam. (*Ibid.*, pp. 52–55). An account is given of the typical types and positions of the fractures met with in practice in welded or mainly welded ships.—C. O.

**Brittle Failure of American Ship Plates.** W. Barr. (*Ibid.*, pp. 58–68). An account is given of an examination of the structure of fractured plates from American ships and the chemical composition, microstructures,

and properties of eleven American and nine representative British ship plates are compared. The outstanding differences noted were in the manganese contents and the Izod impact strengths, both of which were greater in the British steels.—C. O.

**Fracture and Notch Toughness in Ductile Metals.** E. Orowan. (*Ibid.*, pp. 70–78). The "macroscopic" nature of ductile and brittle fracture, Ludwik's triaxial-stress theory of notch brittleness, the relationship between notch brittleness and velocity of crack propagation, elastic superstressing, and the meaning of the notch impact test are discussed.—C. O.

**Fracture of Metals—Some Theoretical Considerations.** N. F. Mott. (*Ibid.*, pp. 79–85). An outline is given of the present state of the theory of fracture in brittle substances, and its application to ductile materials such as metals is discussed mathematically.—C. O.

**Fundamental Physical and Metallurgical Aspects of Brittle Steel.** D. E. J. Offord. (*Ibid.*, pp. 94–96). Examples are quoted of brittle fractures which have occurred in ships of the Royal Navy, and a short account is given of researches carried out by the Admiralty in connection with brittle failure, using $\frac{1}{2}$-in. mild-steel plates "dished" by underwater explosions. —C. O.

**An American Point of View.** E. M. MacCutcheon. (*Ibid.*, pp. 98–100). A brief summary is made of American research work on brittle failures in welded ships and brittleness in mild steel.—C. O.

**Stress Determination by Brittle Coatings.** G. Ellis. (Mechanical Engineering, 1947, vol. 69, July, pp. 567–571). The equipment and methods employed for the measurement of static, dynamic, and residual stresses in metal parts are described. An example shows the improvements to the design of a small crankshaft which were made from data obtained in this way.—R. A. R.

**Forging Failure Caused by Carbon Pick-Up.** M. B. Graham. (Iron Age, 1947, vol. 160, July 24, pp. 65–67). An investigation of a fracture in a forged anchor-chain link is reported. The failure is considered to have been caused by carburization from thermally decomposed fuel oil during a heating operation in a box-type oil-fired furnace.—C. O.

**Repair to Winder Gear.** D. G. Wishart. (Journal of the South African Institution of Engineers, 1947, vol. 45, May, pp. 310–316). A metallurgical examination of a cast-steel winder gear which had failed in service by the fracture of six teeth is described. The gear was repaired by bolting to it a forged steel insert, which proved satisfactory in further service. The original failure is considered to be due to insufficient risers on the casting, which allowed shrinkage cavities to be formed at the base of the teeth. Attempts had been made to improve the casting by welding the visible cavities.—C. O.

**Flaking in Alloy Steels.** S. W. Poole. (Iron Age, 1947, vol. 160, July 17, pp. 42–46). Theories of the cause of flaking in alloy steels are discussed in a very general manner as a basis for an outline of heat-treatment practice for alloy steels. Methods for detecting flakes in billets and blooms are mentioned.—C. O.

**Occurrence of Intergranular Fracture in Cast Steels.** C. H. Lorig and A. R. Elsea. (American Foundrymen's Association, 1947, Preprint No. 47-2). The causes of a peculiar smooth undulating fracture in test bars of some cast steel specimens were investigated. The surfaces observed on the fracture were found to be the primary austenite grain boundaries established at the time of casting. The following causes of this peculiar intergranular fracture are advanced as the result of this investigation: (1) Aluminium nitride precipitation at the primary grain boundaries; (2) ferrite precipitation as a network at the primary grain boundaries; (3) massive carbides in the primary grain boundaries; (4) extreme cases of sulphide inclusions; and (5) internal hot tears.—R. A. R.

**An Oil-Powder Method of Flaw Detection.** B. Ronay. (Welding Journal, 1947, vol 26, May, pp. 407–409). A brief description is given of a method of detecting surface defects in complex structures such as Diesel-engine frames and crankshafts. A penetrating oil compounded with a red dye is applied to the surface, followed by a white powder. Cracks or other flaws are indicated within one minute by sharp red lines against the white background.—C. O.

**Symposium on the Failure of Metals by Fatigue.** (University of Melbourne, Dec., 1946). Abstracts of Preprints Nos. 11 to 27 are given below. (*See* vol. 157, Sept., pp. 153–154 for abstracts of the first 10 papers).—R. A. R.

**Methods of Investigating the Fatigue Properties of Materials.** W. W. Johnstone. (Symposium on the Failure of Metals by Fatigue, University of Melbourne, Dec., 1946, Preprint No. 11). This paper is an introduction to methods of investigating the fatigue properties of materials in that it describes the basic test procedures and some of the common influencing factors which might be encountered. Mechanical methods as used at the Council for Scientific and Industrial Research, Division of Aeronautics, Melbourne, are described in some detail with brief notes concerning other methods.

**Determination of Stress Concentration Factors.** F. S. Shaw. (Symposium on the Failure of Metals by Fatigue, University of Melbourne, Dec., 1946, Preprint No. 12). This paper reviews the better known methods of determining stress-concentration factors. They include mathematical methods, *i.e.*, the mathematical theory of elasticity which is based on the postulation of an ideal structureless material, photo-elastic and various other types of indirect experimental methods. The relative merits of the methods are discussed and the use of stress-concentration factors in design is mentioned.

An appendix is included which, in the form of a nomogram, summarizes the stress-concentration factors for a variety of different types of stress raisers. The nomogram is due to Neuber, and is taken from his book "Kerbspannungslehre."

**Photo-Elasticity and Stress Concentration.** W. H. H. Gibson. (Symposium on the Failure of Metals by Fatigue, University of Melbourne, Dec., 1946, Preprint No. 13). This paper deals with the technique of photo-elasticity as applied to problems of stress concentration, and particularly with the results of experience in the Charles Kolling Laboratory, University of Sydney. The most direct results can be obtained when the stress concentration occurs on a free boundary. Cutting tools and methods used in the preparation of models are discussed, together with edge effects and annealing of the photo-elastic material. Thickness ratio is defined, and used as a means of estimating the limiting radius for a notch, groove, or similar stress raiser, below which results are likely to become unreliable. Stress determination at loaded boundaries and internal points is discussed, with particular reference to the Coker Lateral Extensometer. The "frozen-stress" technique which makes photo-elasticity available for three-dimensional problems, is briefly discussed.

**Fatigue Tests on Four Welded H-Beams.** A. L. Percival and R. Weck. (Symposium on the Failure of Metals by Fatigue, University of Melbourne, Dec., 1946, Preprint No. 14). The paper describes a method of testing large beam specimens by resonant vibration excited by a mechanical oscillator. Nodal support confines the vibration to the specimen and avoids the use of heavy foundations and the loss of power to the supports. The oscillator consists of two eccentric masses geared together to rotate in opposite directions and is driven by a D.C. motor, the speed of which is automatically controlled to maintain a constant amplitude of vibration of the specimen.

Mathematical relationships between the stress, amplitude, and position of nodes are derived for a uniform beam with a central mass. The specimens used were welded **H**-beams 6 in. × 5 in. in section and 12 ft. 6 in. long.

**Residual Stresses, Their Measurement and Their Effects on Structural Parts.** G. Sachs. (Symposium on the Failure of Metals by Fatigue, University of Melbourne, Dec., 1946, Preprint No. 15). The method for measuring residual stresses developed by the author in 1927 and its limitations and applications are described. The method consists of measurement of changes in length and outside diameter after boring out rods, and tubes, the changes being due to the removal of material containing residual stresses. The method is limited to solid and hollow cylinders containing stresses which vary only along the radius but are constant along the axis of the cylinder and its circumference. The mathematical details of the method are derived in an appendix. The relations between the residual stresses and the strength properties are discussed.

**The Design of Cylindrical Shafts Subjected to Fluctuating Loading.** G. G. McDonald. (Symposium on the Failure of Metals by Fatigue, University of Melbourne, Dec., 1946, Preprint No. 16). In this paper, the "maximum elastic distortional energy" theory of failure is applied to the case of a cylindrical shaft subjected to combined fluctuating bending, twisting, and direct loads. An expression is derived for the particular case of combined fluctuating bending and twisting moments. The method of approach is simpler than that adopted by either T. Timoshenko or J. Marin, as expressions for the design of shafts subjected to combined fluctuating bending and twisting are derived. Experimental results on combined loading of cylindrical specimens confirm the formula.

**Fatigue of Bolts and Studs.** J. G. Ritchie. (Symposium on the Failure of Metals by Fatigue, University of Melbourne, Dec., 1946, Preprint No. 17). The paper is a survey (with 47 references) in which the published information relating to the fatigue of bolts, studs and nuts is reviewed.

**The Fatigue of Welded Steel Tubing in Aircraft Structures.** C. J. Osborn. (Symposium on the Failure of Metals by Fatigue, University of Melbourne, Dec., 1946, Preprint No. 18). This paper is a brief review of the literature concerned with fatigue in tubular steel aircraft structures.

**Notch Sensitivity of Metals.** M. S. Paterson. (Symposium on the Failure of Metals by Fatigue, University of Melbourne, Dec., 1946, Preprint No. 19). The paper is a review of published articles on notch-sensitivity in fatigue of metals. Sources of stress concentration are listed, and means of measuring their effects in fatigue are summarized. It is concluded that, although there seems to be a material property involved in notch effects, there are many associated factors such as stress gradients and the influence of multi-axial stresses which do not permit a clear perception of the part played by the particular characteristics of a given model. The need for more co-ordinated work on many aspects of notch-sensitivity is stressed.

**Composition and Physical Properties of Steel in Relation to Fatigue.** D. O. Morris. (Symposium on the Failure of Metals by Fatigue, University of Melbourne, Dec., 1946, Preprint No. 20). A review of the literature indicates that ultimate tensile strength and hardness are the only properties of ferrous materials which bear a definite relationship to fatigue properties, yield point, elongation, reduction of area, notch-impact resistance; work-hardening capacity and damping capacity apparently have little or no effect. In view of the importance attached to notch-impact tests in British and Australian specifications, a more critical treatment is given of the relation of this test to fatigue properties.

Results of experimental work on two alloy steels, each heat-treated to give high and low Izod impact figures, support the opinion that impact resistance of notched bars bears no discernable connection with the fatigue properties of ferrous alloys. The normal constituents of steels appear to affect the fatigue properties only in so far as they alter the ultimate tensile strength and hardness.

Attention is drawn to the fact that phosphorus tends to increase the fatigue limit, as do carbon, manganese, nickel, and chromium. The opinion is expressed that sulphur up to at least 0·10% does not appreciably affect the fatigue properties of steels, either longitudinally or transversely (notwithstanding the formation of inclusions), and experimental work carried out on high-sulphur free-cutting steels supports this belief.

**Fatigue Problems in the Gas Turbine Aero Engine.** A. R. Edwards. (Symposium on the Failure of Metals by Fatigue, University of Melbourne, Dec., 1946, Preprint No. 22). The major sources of vibration in gas turbines are discussed and it is noted that vibrations arising from aerodynamic causes predominate. Mechanically induced vibrations are negligible, due to the absence of reciprocating parts. Various design features which aim particularly at the alleviation of vibration and fatigue troubles are described. It is pointed out that, at present, design calculations can only be made for the steady stresses, the superimposed vibrational stresses being taken care of by ensuring that dangerous frequencies are not excited at normal running speeds.

The problems involved in the fatigue-testing of turbine blades are described and the limitations of existing laboratory testing equipment discussed. The loads on blades are complex combinations of steady centrifugal tension with steady and fluctuating bending and torsion which are difficult to reproduce in a testing machine working at temperatures in excess of 600° C. The influence of creep on endurance stresses as determined by present laboratory methods, at frequencies which are only a small fraction of the vibration frequencies encountered in the operating turbine, is noted.

**The Prevention of Fatigue Failures in Metal Parts by Shot Peening.** J. G. Brookman and L. Kiddle. (Symposium on the Failure of Metals by Fatigue, University of Melbourne, Dec., 1946, Preprint No. 23). A detailed account of the theory of the use of shot-peening is presented, particular reference being paid to Almen's work, and the problems of distortion, complementary stresses, and stress concentrations.

Factors necessary in a specification for peening are then discussed, including the selection of areas, coverage, shot type, shot size, and intensity. A new method for measuring intensity has been developed and is described. Practical applications of the treatment are indicated, and the possibility of obtaining large increases in life is discussed. Figures of the improvement in life of some machine parts treated by the authors are given, and an unusual example of the reduction in notch-sensitivity of a steel spring, heat-treated to a hardness of 750 (diamond pyramid) and working under a cyclic stress of 102 tons/sq. in. is cited.

**Failures of Railway Materials by Fatigue.** H. O'Neill. (Symposium on the Failure of Metals by Fatigue, University of Melbourne, Dec., 1946, Preprint No. 24). Fatigue failures were noticed by railway engineers as early as 1843, and led to the first laws of fatigue being formulated by Wöhler in 1852. Rails, tyres, wheel-centres, axles, fire-boxes, and stay-bolts, have all exhibited fatigue. The type of fatigue failure in all these parts is discussed, reference being made to the accelerating effect of corrosion and also to the incidence of fatigue cracks in material under compression. Instances of fatigue failure of parts in transit are quoted.

**The Influence of Radial Pressure from a Press Fit on the Endurance Limit of Axles and Crank Pins.** G. W. C. Hirst. (Symposium on the Failure of Metals by Fatigue, University of Melbourne, Dec., 1946, Preprint No. 25). This paper is a summary of the work done since 1936 on the fatigue failure of axles and its relation to press fits, by members of the staff of the Redfern Laboratory of the New South Wales Railways. The evolution of opinion regarding the cause of fatigue cracking in the wheel seats of railway axles is traced from the "notch effect" theory advanced by Kuhnel to the later theory based on the pressure of induced tensile stresses at the surface and fretting corrosion at the mating surfaces. The possibility of employing cast-iron wheel centres as a means of minimizing fretting corrosion is discussed.

**Fatigue Failure of Axles of Car and Wagon Railway Rolling Stock.** E. Connor. (Symposium on the Failure of Metals by Fatigue, University of Melbourne, Dec., 1946, Preprint No. 26). The subject is considered from the practical aspect, and relates closely to experience of car- and wagon-axle failures in the Victorian Railway Department. Reference is made to the design of axles and wheels, and the materials used, and to the types of failure experienced. Failure of those portions of the axles carrying the wheels is dealt with at length. This type constitutes the greatest proportion of failures, and fatigue-cracking in the wheel seat is the principal reason for condemning car and wagon axles.

Normal design stresses are considerably below the fatigue limit of the axle steel, and brief reference is made to the possible causes of the fatigue limit being exceeded within the wheel seat. Methods of detecting the presence of cracks hidden by the wheel boss are discussed; removing the wheel is still the only positive means of doing this.

Reference is made to the extensive work carried out at the Timken Laboratory for the Association of American Railroads, and various possible modifications in design, material and finish that might help to minimize the incidence of fatigue cracking in axle-wheel seats are discussed.

It is considered that no real solution has yet been found, but suggestions are made as to precautions that may diminish the frequency of fatigue-cracking.

**Types of Fatigue Failure in the Steel Industry.** W. O. Beale. (Symposium on the Failure of Metals by Fatigue, University of Melbourne, Dec., 1946, Preprint No. 27). The fatigue failures met with in the heavy steel industry are classified according to apparent cause or location, and the relative frequencies are given. The various types are then considered and the corrective measures used to eliminate the failures are indicated.—R. A. R.

**Fatigue Tests by the Resonance Vibration Method on Four Welded H-Beams.** A. L. Percival and R. Weck. (Transactions of the Institute of Welding, 1947, vol. 10, June Supplement, pp. 6–22.) An interim report is presented by the F.E.8 Committee on "Behaviour of Welded Structures under Dynamic Loading" of the British Welding Research Association. The report describes work on the development of a method of testing structures under alternating loading; in particular, reference is made to the use of a resonance-vibration method for testing welded **H** beams to destruction by bending-fatigue.—C. O.

**Symposium on Testing of Parts and Assemblies.** (American Society for Testing Materials, 1947, Technical Publication No. 72). This symposium was sponsored jointly by the American Society for Testing Materials and the Society for Experimental Stress Analysis. Abstracts of the papers presented, which relate to fatigue testing, are given below.—R. A. R.

**Endurance—A Criterion of Design.** W. T. Bean, jun. (*Ibid.*, pp. 25–40). The use of brittle lacquer coatings to determine the position of stress concentrations in aero-engine crankshafts, connecting rods and bearing caps, and to establish the cause of failure of such parts is described.—R. A. R.

**Pneumatic Fatigue Machines.** F. B. Quinlan. (*Ibid.*, pp. 41–46). Details are given of the principles and construction of pneumatic bending and torsional fatigue testing machines for testing gas-turbine buckets at normal and at elevated temperatures. —R. A. R.

**Automotive Rear Axles and Means of Improving their Fatigue Resistance.** O. J. Horger and C. H. Lipson. (*Ibid.*, pp. 47–75). The results of rotating-bending fatigue tests on 88 hardened and tempered motor-car rear axles are presented and discussed. Unstraightened axles had about 25% higher endurance limit than straightened ones. The cold-straightening had induced tensile stresses of about 120,000 lb./sq. in. at the surface. The endurance limit of straightened axles was increased about 300% by shot-peening. Some carburized axles accidentally becames slightly decarburized in heat-treatment; their fatigue resistance was not improved by shot-peening.—R. A. R.

**Stress Concentration and the Fatigue Strength of Engine Components.** C. Gadd, N. A. Ochiltree, and A. Zmuda. (*Ibid.*, pp. 76–86). The endurance limits of parts of complicated shape (a crankshaft web and a connecting rod) were calculated from measurements of maximum local strain at points of stress concentration and these were compared with fatigue strength data obtained by testing sufficient specimens to permit the construction of a complete $S$-$N$ diagram (stress/number-of-cycles). The comparison indicates that the calculated endurance limits are reasonably valid.—R. A. R.

**Pneumatic Fatigue Machines.** F. B. Quinlan. (Proceedings of the American Society for Testing Materials, 1946, vol. 46, pp. 846–850). A short description is given of the construction and operation of a machine for the fatigue-testing of gas-turbine buckets. One end of the specimen

is caused to vibrate between two opposed cylinders, from each of which in turn it receives an impulse by means of an air stream. The tests can be made at temperatures up to 1700° F. A pneumatic torsional fatigue-testing machine is also described.—C. O.

**A Method of Detecting Incipient Fatigue Failure.** H. W. Foster. (Proceedings of the Society for Experimental Stress Analysis, 1947, vol. 4, No. 2, pp. 25–31). The technique of detecting the formation of a very small crack on the surface of a specimen subject to fatigue is described. Annealed round copper wire 0·002 in. in dia. is cemented to the surface, from which it is electrically insulated. The formation of a crack causes the wire to break, thus interrupting an electrical circuit. Examples of the application of the technique are illustrated.—C. O.

**A Machine for Fatigue Testing Full-Size Parts.** A. F. Underwood and C. B. Griffin. (Proceedings of the Society for Experimental Stress Analysis, 1947, vol. 4, No. 2, pp. 32–38). An apparatus which permits alternating tests in tension, compression, or tension and compression to be made on full-size machine parts is briefly described, and its application is illustrated by examples.—C. O.

**Civil Engineering Construction in Switzerland.** M. Roš. (Revue Technique Luxembourgeoise, 1946, vol. 38, Oct.–Dec., pp. 17–31). Part VI of this conference on civil engineering in Switzerland is devoted to steels. The most important researches, in Switzerland, during the period 1935–1945, were on fatigue, welding, and the safety factors of structures.—R. F. F.

**Corrosion Fatigue.** G. T. Dunkley. (Mechanical World, 1947, vol. 122, Aug. 8, pp. 137–141). An attempt is made to explain simply the mechanism of corrosion-fatigue failures. Methods of overcoming the trouble are suggested. Both steels and non-ferrous metals are dealt with.—R. A. R.

**Influence of the Surface on the Fatigue of Metals.** M. Roš. (Commission Technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, Paris, 23–26 Oct., 1945, pp. 207–218).

**The Spreading of Liquids on Metals as a Function of their Surface Condition.** R. Morlock. (Commission technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, Paris, 23–26 Oct., 1945, pp. 219–222).

**Influence of Surface Condition on the Conduction of Contacts.** P. de la Gorce. (Commission Technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, Paris, 23–26 Oct., 1945, pp. 223–226).

**The Part Played by Chemical Reactions in the Phenomena of Friction and Wear.** C. H. Desch. (Commission Technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, Paris, 23–26 Oct., 1945, pp. 235–236).

**The Progress of Failure in Metals as Traced by Changes in Magnetic and Electrical Properties.** P. E. Cavanagh. (American Society for Testing Materials, 1947, Preprint No. 26). The relative changes in magnetic and eddy-current losses during normal endurance tests in rotating-beam machines have been determined for six metals at loads above and below the endurance limit. The development of failure at loads above the endurance limit can be traced from these changes, which may be of practical use in testing ferrous and non-ferrous metals under service loads. No significant difference in endurance life was produced by increasing the speed of testing, although the amount of slip was materially reduced. —C. O.

**Report on Special Alloy Addition Agents.** (American Iron and Steel Institute, Nov., 1942, Contributions to the Metallurgy of Steel, No. 9). A series of hardenability curves for a number of alloy steels is presented. They indicate the changes in the hardness characteristics in relation to the amounts of alloying elements present. —R. A. R.

**Tentative Hardenability Bands.** (American Iron and Steel Institute, July, 1944, Contributions to the Metallurgy of Steel, No. 11). Committees appointed by the War Engineering Board, the Society of Automotive Engineers, and the American Iron and Steel Institute have collaborated and produced tables of end-quench hardenability bands for a number of constructional alloy steels which are here presented.—R. A. R.

**Calculation of the Standard End-Quench Hardenability Curve from Chemical Composition and Grain Size.** (American Iron and Steel Institute, Feb., 1946, Contributions to the Metallurgy of Steel, No. 12).—R. A. R.

**Some Aspects of Hot Hardness Testing.** K. G. Robinson. (Metallurgia, 1947, vol. 36, May, pp. 45–46). Sources of error in the measurement of the hardness of metals at elevated temperatures are discussed, and a comparison is made of the relative merits of static and impact testing methods.—C. O.

**Temper Brittleness in Low-Alloy Steel.** W. J. Holtman and W. C. Keil. (Quarterly of the Colorado School of Mines: Iron and Coal Trades Review, 1947, vol. 154, June 6, pp. 1033–1034). Investigations were made to determine whether temper brittleness was the cause of unaccountable failures in boiler and rail steels. The former showed definite evidence of temper brittleness, but the latter showed little change in impact energies that might be attributed to temper brittleness. The increase in the impact values of the rail steels after heat-treatment were attributed to partial spheroidization. The zephiran-picric solution was satisfactory as a metallographic etching medium.—R. A. R.

**A Micro-Hardness Tester.** H. Lloyd and R. Jeffrey. (Journal of Scientific Instruments, 1947, vol. 24, July, pp. 186–189). A description is given of a simple instrument to be used in conjunction with a metallurgical microscope for determining the hardness of a material at microscopically determined points. Typical test results are presented.—C. O.

**Hardness and Hardenability in Carbon and Alloy Steels.** (Product Engineering, 1947, vol. 18, July, pp. 141–143). A short account is given of the influence of carbon and other alloying elements on the hardness and hardenability of steels.—C. O.

**End-Quenched Specimens—Polishing and Hardness Measurement of the End-Quenched Jominy Bar.** W. I. Pumphrey. (Iron and Steel, 1947, vol. 20, July, pp. 371–372). A technique for polishing Jominy test-bars after end-quenching and a fixture for determining accurately the position of hardness measurements are described.—C. O.

**The Part Played by Surface Conditions in Hardness Measurements.** P. Bastien and A. Popoff. (Commission Technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, Paris, 23–26 Oct., 1945, pp. 187–206).

**An Appraisal of Hardenability Band Specifications for Alloy Steels.** D. H. Ruhnke. (American Iron and Steel Institute, May, 1947, Advance Copy). The results of making several hundred alloy-steel heats to the hardenability specifications of the American Iron and Steel Institute Alloy Technical Committee are summarized, and possible modifications to the hardenability bands suggested by experience are indicated.—C. O.

**Magnetic Particle Inspection of Weldments.** S. L. Henry. (Metal Progress, 1947, vol. 52, July, pp. 88–90). A report is made on a discussion on the magnetic-particle method of weld testing organized by the Magnaflux Corporation, Chicago.—C. O.

**Magnetic Tests of Spot Welds in Stainless Steels.** (Engineering, 1947, vol. 164, Aug. 22, pp. 177–178, 180). It has been found that the permeability of stainless steel is increased by welding, the increase being greater for good spot welds than for bad ones. An instrument for utilizing this change in permeability for the inspection of welds, known as the Metroflux captive-fluid magnetic detector is described and its operation illustrated. It consists of a flat rectangular transparent plastic cell containing a suspension of magnetic particles in light oil.—C. O.

**A Permeameter for Metals Used in Cathode-Ray and Television Tubes.** H. J. Evans. (Proceedings of the American Society for Testing Materials, 1946, vol. 46, pp. 1119–1125). The construction and calibration of an inexpensive instrument for the rapid routine measurement of the permeability of paramagnetic alloys are described. The instrument is based on an adaptation of the Gouy method, and it can be used for testing materials of a wide variety of shapes.—C. O.

**The Use of High Permeability Materials in Magnetometers. The Application of a Saturated Core Type Magnetometer to an Automatic Steering Control.** L. D. Armstrong. (Canadian Journal of Research, Section *A*, 1947, vol. 25, May, pp. 124–133). Two types of magnetometers using high-permeability materials are described: (*a*) Those with a field which does not fully saturate the core, which also have a secondary harmonic output; and (*b*) those with a saturated core, which give a peak signal output. The application of the latter type of instrument to automatic steering control is described in detail.—C. O.

**Modern Magnetic Materials.** H. E. Finke. (Materials and Methods, 1947, vol. 25, June, pp. 72–76). The properties and applications of the magnetic alloys, Alnico, Cunife, Cunico, Vectolite (a sintered mixture of ferrous and ferric oxides and cobalt oxide), and Silmanal (a silver-manganese-aluminium alloy) are briefly summarized.—C. O.

**Apparatus for Measuring Power Loss in Small Ferromagnetic Samples Subject to an Alternating Magnetic Field.** K. H. Stewart. (Journal of Scientific Instruments, 1947, vol. 24, June, pp. 159–162). An apparatus is described which enables the power losses of "soft" magnetic materials, such as steel transformer sheets, to be measured at known flux densities on specimens 15 × 1 × 0·03 cm. Electronic methods are used to obtain the necessary sensitivity.—C. O.

**Report on Permanent Magnet Alloys Produced in Japan.** (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./215–311 : H.M. Stationery Office).

**Japanese Magneto-Strictive Materials.** (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./314 : H.M. Stationery Office). Synopses are given of Japanese research reports on the magnetostriction of iron–aluminium alloys.—C. O.

**A New Type of Magnetic Flaw Detector.** C. H. Hastings. (American Society for Testing Materials, 1947, Preprint No. 22). An account is given of the development of a method for detecting flaws in the bores of ferrous tubes and cylinders. The specimen to be inspected is magnetized by direct current. Flaws such as cracks cause magnetic leakage, which can be detected and automatically recorded by an electromagnetic pickup coil and indicator. The sensitivity may be varied to detect cracks as shallow as 0·05 in. or to pass over the shallower cracks and indicate only the deeper ones.—C. O.

**Use of Magnaflux and Zyglo for Non-Destructive Testing.** K. E. Glover. (Industrial Radiography, 1947, vol. 5, Spring Issue, pp. 41–44). The applications of the wet and dry Magnaflux methods for the non-destructive testing of cast, welded, and machined ferro-magnetic materials are outlined. A short account is also given of the properties of "Zyglo"—a fluid which is able to penetrate into very small discontinuities and fluoresce under near-ultra-violet light. In its applications Zyglo is similar to Magnaflux, but in addition it can be used to inspect non-magnetic materials, such as plastics, ceramics, and glass.—C. O.

**Testing Materials for Internal Discontinuities with Supersonic Echoes.** J. W. Dice. (Industrial Radiography, 1947, vol. 5, Spring Issue, pp. 29–33). The theory and operation of the Sperry supersonic reflectoscope are described and illustrated.—C. O.

**The Automatic Sonigage.** W. S. Erwin and G. M. Rassweiler. (Iron Age, 1947, vol. 160, July 24, pp. 48–55). The construction and operation of an ultrasonic instrument for the measurement of the wall thickness of long tubes and the detection of flaws in heavy steel sections are described.—C. O.

**Supersonic Inspection for Internal Fissures in Cast Rolls.** J. Dugan. (Steel, 1947, vol. 121, July, pp. 80–81, 95–97). The use of the Sperry supersonic reflectoscope for inspecting cast rolls is described.—C.O.

**Supersonic Testing of Steel.** R. R. Webster. (American Iron and Steel Institute, May, 1947, Advance Copy). A short account is given of the elementary theory of the transmission of sound waves in steel, and the "shadow" and "reflection" methods of detecting defects are explained.—C. O.

**Small Parts Inspection by Automatic Gaging.** C. W. Warren. (Iron Age, 1947, vol. 159, June 19, pp. 64–65). A general description is given of an automatic electronic gauge, known as the Limitron, for the acceptance or rejection inspection of parts up to 1½-in. maximum dimension. With manual feed, up to 5000 pieces may be handled per hour. The instrument can be adapted for operation by blind or disabled people.—C. O.

**Vibration Testing Technique and Its Use in Improving Designs.** J. A. Dickie. (Product Engineering, 1947, vol. 18, July, pp. 115–119). An account is given of methods of vibration testing and their application in the design of parts subjected to displacement, vibration or resonance in service.—C. O.

**Dichotomic Determination of Minerals.** P. Bresson. (Revue de l'Industrie Minérale, Mémoires, 1946, Nov., pp. 407–428). Dichotomy is a process applied to the determination of natural species. Its name, which signifies "cut in half," explains the process. Objects to be examined, are divided in two groups according to whether they possess a given property. Each group is divided again in two groups, according to the presence or absence of a new property. This process of division is continued until, not a group, but a single object possessing or lacking this property, is obtained. This will give the name of the object. The author discusses the method and its application to mineralogy. A table and the method of applying it to determine minerals are given.—R. A. R.

**High Temperature Testing.** W. E. Kuhn. (Canadian Metals and Metallurgical Industries, 1947, vol. 10, May, pp. 20–22, 43; June, pp. 27–29, 50). The effect of high temperatures on the mechanical properties of metals is discussed and methods of testing tungsten and molybdenum steels at high temperatures are described.—R. A. R.

**Problems Involved in the Fabrication of High Temperature Alloys.** G. Mohling. (American Iron and Steel Institute, May, 1947, Advance Copy). The properties and heat-treatment of the alloys, *S*-588, *S*-590, and *S*-816, developed by the Allegheny Ludlum Steel Corporation are summarized. These alloys are mainly applied in the manufacture of turbine rotors and buckets, operating

at temperatures of 1200–1500° F. Precision casting is probably the most economical way of making buckets, although the percentage of rejections is high. The high-temperature alloys are difficult to machine, but marine gas-turbine buckets have been machined from rolled rhomboid sections after heat-treatment; drop-forging has also been used with some success.—C. O.

**Behaviour of Metals at High Temperatures.** Vinçotte. (Mémoires de la Société Royale Belge des Ingénieurs et des Industriels, 1945, Série B, No. 2, pp. 349–362). The results of creep and tensile tests on steels at high temperatures are discussed.—J. C. R.

**The Emissivity of Hot Metals in the Infra-Red.** D. J. Price. (Proceedings of the Physical Society, 1947, vol. 59, Part 1, Jan. 1, pp. 118–131). The emissivity of incandescent metals has been measured for wave-lengths of 1·0–4·5 μ, results being given for iron, platinum, molybdenum, copper, and nickel. From the emissivity values obtained, and from those given by other investigators, it appears that for a wave-length (usually in the near infra-red) peculiar to each metal the emissivity is constant over a large range of temperature.—D. R. S.

**The Temperature Variation of the Emissivity of Metals in the Near Infra-Red.** D. J. Price. (Proceedings of the Physical Society, 1947, vol. 59, Part 1, Jan. 1, pp. 131–138). Evidence of the existence of a wave-length, peculiar to each metal, for which the temperature coefficient of emissivity is zero is analysed and discussed.—D. R. S.

**Heat Treatment of some Chromium–Nickel Alloys.** H. A. Campbell. (Iron Age, 1947, vol. 159, June 5, pp. 74–79). The effects of heat-treatment on the physical properties of sheets and tubes of the common chromium–nickel steels and alloys are considered. Precautions which should be taken during heat-treatments are mentioned.—C. O.

**Interpretation of Creep and Stress-Rupture Data.** F. B. Foley. (Metal Progress, 1947, vol. 51, June, pp. 951–958). Methods of creep testing, the interpretation of results, and the mechanism of flow and fracture under long-continued loads at high temperatures are reviewed, and methods of improving the service of existing alloys and of developing new alloys for use under extreme conditions are suggested.—C. O.

**Observations on Conducting and Evaluating Creep Tests.** W. Siegfried. (Journal of the Iron and Steel Institute, 1947, vol. 156, June, pp. 189–207). The paper describes sustained-load tests carried out on various highly heat-resistant alloys used in the construction of gas turbines. The results of these tests are evaluated in the light of the main problems presented by gas-turbine design. A much longer life is required of stationary gas turbines for power plants and marine propulsion duties than of aircraft gas turbines. The question of extrapolation over long periods (more than 10 years) is therefore dealt with. The tests described also broach the problems of three-dimensional stressing at high temperatures and the influence of notches on hot strength. The results of sustained-load tests on smooth and notched bars at high temperatures are set forth and discussed. A decisive influence on deformation figures in the sustained-load test and on the notch toughness is exercised by the testing time. Curves are given for various steels which furnish a good criterion of their toughness.

**Progress in Steel Manufacture.** A. J. K. Honeyman. (Iron and Coal Trades Review, 1947, vol. 154, June 20, pp. 1126–1130, 1149). The author outlines the progress which has been made in recent years in the development of steels for constructional work, shipbuilding, and pressure vessels. Reference is made to the problems raised by welding, machinability, surface-hardening, and subnormal temperatures.—C. O.

**Some Post-War Credits in Alloy Steels.** J. F. Sewell. (Iron and Coal Trades Review, 1947, vol. 154, June 20, pp. 1118–1125). Certain of the outstanding wartime metallurgical advances have not lost their importance in peacetime. Among these are the rationalization of steel specifications, the development of creep-, heat-, and corrosion-resistant alloys, particularly in connection with gas-turbine and jet-propulsion work, the improvement in machinability of steels brought about by the addition of lead, and the nitriding of bearings.—C. O.

**Correlation of Tension Tests with Relaxation Tests.** E. P. Popov. (Journal of Applied Mechanics, 1947, vol. 14, June, pp. A-135–A-142). A method for obtaining a satisfactory estimate of relaxation from a normal tensile creep curve is explained. The accuracy of various methods of calculating simple relaxation is judged by comparison with test results. The usual methods are shown to be inadequate, and the analytical methods which appear satisfactory are extended to cover relaxation with an elastic "follow up."—C. O.

**Creep and Some Creep-Resisting Alloys.** G. Burns. (Extract from "Papers on Engineering Subjects," 1947, issued by the Admiralty: Metallurgia, 1947, vol. 36, June, pp. 63–65). A simple account of the phenomenon of creep and its influence on engineering design is given. The principal types of creep-resisting alloys are classified.—C. O.

**The Use of Metals Under High-Temperature Conditions.** J. M. Robertson. (Iron and Coal Trades Review, 1947, vol. 154, June 20, pp. 1135–1142). The general relationships between stress, corrosion, temperature, and time are considered from the viewpoint of the behaviour of metals under service conditions, particularly at high temperatures. Under high-temperature conditions creep becomes of paramount importance and the character of corrosion is quite different from that at room temperatures. Properties such as fatigue and hot-corrosion resistance, resistance to embrittlement, structural changes, and precipitation hardening, influence the selection of materials from specific applications, such as in the gas turbine.—C. O.

**Hydrogen in Steel Manufacture.** C. Sykes. (Journal of the Iron and Steel Institute, 1947, vol. 156, June, pp. 155–180). A number of determinations have been made of the hydrogen content of plain carbon and alloy steels at different stages of manufacture; *viz.*, in the electric-arc and open-hearth furnaces, and in ingots, billets, and forgings. The experiments on semi-finished products confirmed results of previous work on steels artificially impregnated with hydrogen and indicated that ductility is reduced with hydrogen contents in excess of 2 c.c./100 g. Even when steel is melted under carefully controlled conditions, hydrogen contents of 4–6 c.c./100 g. are to be expected, which will adversely affect ductility if not removed. A study of the effects of various heat-treatments on hydrogen content and susceptibility has shown that relatively high hydrogen contents do not automatically lead to hair-line cracks. No conclusive evidence was obtained on the question of segregation, although some alloy-steel ingots and forgings showed wide variations in hydrogen content. On the basis of certain assumptions, data on permeability and solubility have been used to calculate values for the diffusivity of hydrogen, which have made possible the prediction of the rate of loss of hydrogen from steels at temperatures down to 400° C., at relatively high hydrogen concentrations. The results of the experiments are discussed in relation to the theories put forward by other

workers on the subjects of hydrogen in steel and hair-line-crack formation.

**Hydrogen and Transformation Characteristics in Steel.** J. H. Andrew, H. Lee, H. K. Lloyd, and N. Stephenson. (Journal of the Iron and Steel Institute, 1947, vol. 156, June, pp. 208–253). A comprehensive study of the evolution of hydrogen from steel has been carried out, and results obtained for 22 different steels, hydrogen-soaked and cooled in vacuum under identical conditions, are reported. It is shown that in all cases relations between hydrogen evolution and transformation characteristics are marked, and that there is a pronounced increase in the rate of evolution corresponding to the gamma–alpha change. The manner in which hydrogen is evolved from a steel is shown to be closely linked with the mode of transformation, but such a correlation does not necessarily determine the amount of hydrogen retained after cooling.

The effect of alloying elements upon hydrogen evolution from steel is discussed, and it is deduced that hydrogen diffusivity in the alpha range may vary with the composition and treatment. It was found that when nascent hydrogen was generated by electrolytic action on the surface of a steel specimen, both the rate of diffusion and the solubility at room temperature depended upon the structure of the steel.

Experiments on the removal of hydrogen from steel under isothermal conditions, as outlined in a previous paper, have been continued, and the results confirmed the conclusion that the optimum temperature of hydrogen removal corresponded with a rapid transformation. Crack formation in isothermally treated specimens has been discussed, and certain anomalous results of crack formation previously observed for plain carbon and nickel steels are explained in terms of the effect of structure upon hydrogen diffusivity and solubility at room temperature.

In the presence of hydrogen, the transformation of a 3% chromium steel under isothermal conditions was slightly slower at 700° C., otherwise hydrogen was found to have no retarding effect upon isothermal transformation. The nature of the isothermal-transformation product has been studied, and it is shown that with a 3% chromium steel containing 0·2% of carbon, 480° C. was found to be the critical temperature dividing the formation of chromium carbide ($Cr_7C_3$) and cementite ($Fe_3C$). Isothermal-transformation diagrams based upon dilatometric measurements are given for the chromium steel as well as for a 3½% nickel steel.

Hydrogen embrittlement was found to vary with the thermal treatment of steel, and it is shown that with a 3% chromium steel the presence of hydrogen to the extent of 3 c.c./100 g. may or may not have an embrittling effect, according to treatments given, and the elongation and reduction of area are affected differently by hydrogen. It was also found that the distribution of hydrogen in a tensile test-piece had a marked effect upon its mechanical properties.

It is considered that hydrogen embrittlement and hair-line cracks are closely associated with each other, and that hydrogen diffusivity and solubility are the controlling factors for both. The view previously expressed to explain hair-line-crack formation has been modified, in that the sudden evolution of hydrogen at the crack formation does not necessarily involve the breakdown of a hydrogen-rich constituent. Whilst hydrogen is the fundamental cause of hair-line cracks, stresses are important in that they may affect the diffusivity and solubility of hydrogen. Unless results of hydrogen diffusivity and solubility in steel for various conditions are available, and the effect of structure and stresses upon them is thoroughly understood, controversies regarding the cause and mechanism of hairline-crack formation cannot be settled.

**The Separation of Gas from Molten Metals.** A. J. Phillips. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2208: Metals Technology, 1947, vol. 14, June). Aspects of the separation of gases from metals during cooling or solidification which have industrial significance are considered quantitatively.—C. O.

**Mechanical Properties NE 9400, 9500 and 9600 Series.** (American Iron and Steel Institute, March, 1943, Contributions to the Metallurgy of Steel, No. 10). This report contains tables of the mechanical properties and hardenabilities of three alloy steels, *viz.* (1) N.E. 9400 steels which are alloyed with manganese, silicon, chromium, nickel, and molybdenum; (2) N.E. 9500 steel, alloyed with chromium, nickel, and molybdenum, and (3) N.E. 9600 steels alloyed with manganese, silicon, and chromium.—R. A. R.

**The Selection and Treatment of High Speed Steel.** (Mechanical World, 1947, vol. 121, Mar. 28, pp. 285–288). The author discusses certain characteristics of the composition, microstructure, and heat-treatment of tool steels which may be of help to the user of such steels in selecting the correct steel for a specific task.—C. O.

**Molybdenum Alpha Irons.** (Alloy Metals Review, 1947, vol. 5, June, pp. 2–6). A series of low carbon steels containing molybdenum 2–5%, were tested in the annealed, normalized, and water-quenched conditions and their physical properties are reported. At the higher concentrations of molybdenum, hardenability is reduced or eliminated, owing to the higher $\alpha$—$\gamma$ transformation temperature. Promising results have been obtained in using these alloys for forging die liners, press-forging die blocks, and cast-iron-pipe moulds.—M. A. V.

**The Silicon Carbide Addition in Gray Iron Automotive Castings.** E. A. Loria, F. S. Kleeman, and A. P. Thompson. (Metal Progress, 1947, vol. 51, Apr., pp. 587–592). A comparison is made of the physical properties and microstructures of grey iron castings, made according to normal practice, with those of similar castings made from iron to which an addition of silicon carbide has been made in the cupola (20 lb. of silicon carbide briquettes per ton of metal). The treated iron was found to have substantially better tensile strength without increased hardness. The metallographic studies showed that the silicon carbide addition was beneficial in promoting small cell size, refined graphite particles, and normal graphite distribution in a matrix of fine pearlite.—C. O.

**High Chromium-Irons.** H. D. Newell. (Metal Progress, 1947, vol. 51, Apr., pp. 617–626). A detailed survey is made of the physical and mechanical properties, microstructure, and applications of the ferritic high-chromium steels, *i.e.*, the commercial non-hardenable alloys containing 12–24% of chromium.—C. O.

**Some Effects of Melting Practice on Properties of Medium-Carbon Low-Alloy Cast Steel.** J. G. Kura and N. H. Keyser. (American Foundrymen's Association, 1947, Preprint No. 47-4). The notched-bar impact properties and the hardenability of medium-carbon, manganese–molybdenum cast steels produced by eight different melting practices were investigated. Three of the practices identified as (*a*) basic, fully oxidized, and blocked; (*b*) basic, fully oxidized, blocked, and finished under a reducing slag; and (*c*) acid, fully oxidized and blocked, were studied more extensively. The principal factors affecting the notched-bar impact

properties appeared to be the sulphur content and sulphide distribution, and these are controlled by the melting practice. In general, if the sulphur content increased or sulphides were found as a network pattern in the grain boundaries, the notched-bar values were low. In these tests the acid steels were, generally, lower in notched-bar impact values than steels produced by the basic practices. This difference, apparently, is related to the higher sulphur content of the acid steels.—R. A. R.

**Effect of Copper Addition Contaminants on Mechanical Properties of Gray Cast Iron.** K. E. Rose and C. H. Lorig. (American Foundrymen's Association, 1947, Preprint No. 47-10). The use of copper-alloy scrap as a source of copper for cast iron may offer some economic advantages if the accompanying elements are not harmful to the iron. Aluminium, antimony, arsenic, beryllium, bismuth, cadmium, lead, tellurium, tin, and zinc were added with 1% of copper to molten grey iron and specimens made from the iron were tested to determine the effects of the addition. Statistical analysis of the results showed that only lead and bismuth were consistently harmful. Zinc may also be harmful. None of the other elements are likely to cause trouble, except for the chill-producing tendency of tellurium. Chemical analysis and the microscope do not reveal the presence of effective amounts of certain harmful elements.—R. A. R.

**Discussion Paper on an Investigation of the Effect of Welding on the Transition Temperature of Navy High-Tensile Low-Alloy Steels.** G. F. Comstock. (Welding Journal, 1947, vol. 26, Apr., pp. 215-s–252-s). The author comments on a paper by Luther, Hartbower, Metius, and Laxar (*see* Journ. I. and S.I., 1947, May, p. 140), and presents data relating to the effect of titanium on the ductile-brittle transition points which in the original paper were given in a different manner. —R. A. R.

**Metallic Titanium and Its Alloys.** R. S. Dean and B. Silkes. (United States Department of the Interior, 1947, Bureau of Mines Information Circular 7381). A summary is made of the preparation, properties, and uses of pure titanium and its alloys. A bibliography of 256 references is appended.—C. O.

**Report on Boron Treated Steel.** (Society of Automotive Engineers, Aug. 2, 1946 : Pamphlet). The Iron and Steel Committee of the Society of Automotive Engineers' War Engineering Board directed from July, 1943, and onwards, an investigation of the merits of boron for the treatment of steel in place of alloying elements which were in short supply. The contents of the nineteen reports submitted to the Committee are summarized.—C. O.

**Diffusion of Beryllium in 13% Chromium and 18% Chromium, 8% Nickel Special Steels.** J. Laissus. (Groupement Français pour le Développement des Recherches Aeronautiques, 1945, Technical Note No. 29, Part 1). The mechanics of the diffusion of beryllium into 13% chromium and 18/8 chromium–nickel steels at various temperatures and the variation of the surface hardness after cementation were studied. Diffusion was effected by heating the specimens in 100-mesh 80% ferro-beryllium heated to temperatures of 800°, 900°, 1000°, 1100° and 1150° C. In general, diffusion occurred in the same way in both steels. Five zones formed and developed as the temperature was raised : (1) Zone of solid solution ; (2) hypo-eutectic zone (solid solution and eutectic) ; (3) euctectic zone ; (4) hypereutectic zone (eutectic and compound) ; (5) zone of compound (the latter difficult to characterize owing to its extreme brittleness). These constituents were much less clearly defined in the 18/8 steel. Cementation with beryllium increased the surface hardness considerably, but if the treatment temperature was raised above 1000° C. the great brittleness developed rendered useless the high degree of hardness produced ; this was confirmed by tests under industrial conditions in which there was a very strong tendency to scaling if the temperature and time of heating were not carefully controlled. The cemented layers were thicker and the surface hardness greater on the 18/8 steel than on the 13% chromium steel for the same treatment.

Part 2 of this publication deals with the "Diffusion of Beryllium in Light and Ultra-Light Metals and Alloys."—A. E. C.

**How to Select Hard-Facing Materials.** H. W. Sharp. (Iron Age, 1947, vol. 160, July 3, pp. 62–66). The author classifies hard-facing materials into four groups : (1) Iron base, containing less than 20% of alloying elements ; (2) iron base, containing 20–50% of alloying elements ; (3) alloys of the cobalt–chromium–tungsten type, with 30–40% of carbide-forming elements ; (4) tungsten carbide contained in steel tubes. The microstructure of each type is correlated with its properties and applications.—C. O.

**Substitute Special Steels for Machinery, and Their Future.** M. Malcor. (Mémoires de la Société des Ingénieurs Civils de France, 1944, vol. 97, June.–Dec., pp. 48–76). The requirements of wartime substitute steels are discussed with particular reference to mechanical tests.—J. C. R.

**Substitute Special Steels.** G. Grenier, (Revue de l'Industric Minérale, Comptes Rendus, 1943, May, pp. 55–59 ; Aug., pp. 107–111 ; Oct. pp. 147–153 ; Dec., pp. 175–180). A general review covering the properties of a wide range of substitute alloy steels is presented.—R. A. R.

**Characteristics of Special Structural Steels and Substitute Steels.** G. Husson. (Revue de l'Industrie Minérale, Mémoires, 1946, Oct., pp. 373–391). Substitute steels are compared with the normal special structural steels with a view to retaining those substitute steels which are as satisfactory as the normal steels.—R. F. F.

**French Special Steels.** G. Genier. (Revue de l'Industrie Minérale, Comptes Rendus, 1946, Nov., pp. 155–159 ; Dec., pp. 176–180 ; 1947, Jan, pp. 1–10 ; Feb., pp. 31–36 ; Mar., pp. 149–156.) This is a general review of French special steels, covering the manufacture, properties, tests, and uses.—R. F. F.

**New Deep Hardening Carburizing Steels.** (Iron Age, 1947, vol. 160, July 24, pp. 62–64). The Carnegie-Illinois Steel Corporation has developed a new series of deep-hardening carburizing steels for gears, shafts, and pinions subject to heavy duty. The properties of these steels, known as U.S.S. Superkore A, AA, B, and C, are compared with those of the more highly alloyed E-3300, 4300, 4800, and 9300 steels which they are intended to replace.—C. O.

**Manganese Steel and the Road Engineer.** L. Sanderson. (Roads and Road Construction, 1947, vol. 25, Sept., pp. 342–344). The work-hardening properties of austenitic manganese steels make them especially suitable for a variety of uses in road-making equipment, such as the lips and teeth of power-shovel dippers, the crawler parts of stripping and other shovels, drag-line bucket chain, quarry-car wheels, crusher-roller shells, etc., where conditions of heavy abrasion are encountered.—J. P. S.

**Gas Containers and Pressure Vessels.** (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1238 : H.M. Stationery Office). The types of gas containers and pressure vessels made by seventeen German firms are listed. In general the quality of these containers compared favourably with similar types made in Great Britain. The most frequently used material

was carbon or low-alloy steel of tensile strength approximately 45 tons/sq. in. The testing of pressure vessels and the production of high-pressure vessels and reaction tubes by " strip winding " are described.—C. O.

**A Comparison of Low-Pressure Vessels Constructed in Compliance with Different Codes or Regulations (with Specific Reference to Liquefied Petroleum Gas).** R. E. Cecil. (Compressed Gas Manufacturers' Association : Welding Journal, 1947, vol. 26, May, pp. 431–433). The requirements of the Interstate Commerce Commission, the American Society of Mechanical Engineers, and the American Petroleum Institute specifications for the wall thicknesses of seamless and welded containers for liquefied petroleum gases are compared.—C. O.

**Unfired Cylindrical Vessels Subjected to External Pressure.** F. V. Hartman. (Transactions of the American Society of Mechanical Engineers, 1947, vol. 69, May, pp. 337–343). Charts are presented for determining the thickness of cylindrical unfired vessels subjected to external pressure, made of carbon or low-alloy steels, Monel, nickel, Inconel, aluminium, and aluminium–manganese alloys. Proposed rules for the reinforcement of openings, testing of vessels, and odd-shaped vessels are discussed.—C. O.

**Master Charts for the Design of Vessels under External Pressure.** D. F. Windenburg. (Transactions of the American Society of Mechanical Engineers, 1947, vol. 69, May, pp. 345–351). Theoretical equations underlying the construction of non-dimensional charts for the design of cylindrical steel vessels subjected to external pressure are presented. The construction and uses of the charts are discussed.—C. O.

**Computing Strength of Vessels Subjected to External Pressure.** R. G. Sturm and H. L. O'Brien. (Transactions of the American Society of Mechanical Engineers, 1947, vol. 69, May, pp. 353–358). The design of vessels subjected to external pressures is discussed. A description is given of the construction and use of collapsing-pressure diagrams and of charts based upon instantaneous moduli of elasticity.—C. O.

**Steels for Use at Elevated Temperatures.** C. Sykes. (Second Hatfield Memorial Lecture : Journal of the Iron and Steel Institute, 1947, vol. 156, July, pp. 321–369). Since 1938 the Brown-Firth Research Laboratories have been developing ferritic and austenitic steels for high temperature work and have been examining methods of production which could be used to work the new materials into various industrial products. This paper describes certain features of this experimental and development work. The paper is restricted to the following main items : (1) The properties of large forgings in ferritic steels ; (2) the development of " R. ex 78 " and similar steels (steel R. ex 78 contains C 0·12% max., Si 1·0% max., Mn 1·0% max., Ni 17–18·5%, Cr 13–14·5%, Cu 3·5–4·5%, Mo 3·5–4·5%, V 0·25% max., and Ti 0·5–1·0%) ; and (3) large austenitic steel forgings. An extensive bibliography on creep- and heat-resisting steels for the period 1937 to 1947 is appended.—R. A. R.

**Requirements of Steel for Gas Turbines.** H. R. Zschokke and K. H. Niehus. (Journal of the Iron and Steel Institute, 1947, vol. 156, June, pp. 271–283). When testing and evaluating heat-resistant steels for gas turbines used in peace time on land and sea, other criteria must be taken into account than in the case of aeroplane turbines, expecially those for military aircraft. This is due to the fact that in peace time a life of many years is required, whereas for aircraft turbines a life of a few hundred hours is enough. This difference is especially important in the evaluation of creep tests on steels used for turbine blades. The alterations of the structure, after long exposure to high temperatures need further exploration, and the value of various methods applied to raise the creep limit must be studied more carefully. Apart from the creep limit, the fatigue strength is of vital importance to the engineer, and the same applies with regard to the corrosion resistance of the blades and the combustion chamber. Here, too, the requirements are much more stringent than for aircraft turbines, since completely different fuels are used. The steels for the rotors, turbine housings, and gas ducts must likewise be selected most carefully on account of the high and varied stresses to which these parts are exposed. Scaling-resistant chromium steels often show a pronounced tendency to embrittlement. When used in combustion chambers they are in addition exposed to corrosion by oxidation and oil residues. Apart from heat resistance, good mechanical properties such as machinability, weldability, forgeability, and bendability are, of course, indispensable in practice.

The gas turbine was introduced in iron and steel works at an early date. Its first use was that of an auxiliary engine for the Brown Boveri Velox steam generator. Gas turbines working at temperatures of 500°–570° C. proved satisfactory for this purpose, the working life in one case exceeding 70,000 hr. Experience has also been gained over many years with gas turbines, at a temperature of 500° C., used in oil refineries for the Houdry cracking process. Combustion turbines for use at 500°–600° C. producing the air for blast-furnaces and steelworks have also been brought on the market by Brown Boveri, and more are under construction, which seems to indicate that the combustion turbine will find interesting applications in iron and steel works.

**Special Steels and Alloys for Gas Turbines.** D. A. Oliver. (Iron and Coal Trades Review, 1947, vol. 154, June 20, pp. 1131–1134). The compositions and properties of the steels and alloys used in the United States, Germany, and Great Britain for the manufacture of gas-turbine flame tubes, guide vanes, rotating blades, and discs, are summarized.—C. O.

**Gas Turbine Forgings.** D. A. Oliver and G. T. Harris. (Institute of Marine Engineers : Iron and Steel, 1947, vol. 20, June, pp. 333–336 ; July, pp. 339–344). **Rotors for Gas Turbines.** D. A. Oliver and G. T. Harris. (Mechanical World, 1947, vol. 21, May 16, pp. 469–472). Problems in the production of solid rotor forgings for use in gas turbines are discussed, and the analyses, characteristics, testing, and applications of various high-temperature steels are reviewed. The paper concludes with some brief notes on the present and future development of axial-flow land and marine gas turbines.—J. R.

**Design and Operation of Some Experimental High-Temperature Gas-Turbine Units.** A. D. Hughes. (Transactions of the A.S.M.E., 1947, vol. 69, Aug., pp. 549–558). Several pieces of equipment designed for testing, under actual service conditions, and materials for use in gas turbines are described.—C. O.

**Metallurgical Considerations of Gas Turbines.** N. L. Mochel. (Transactions of the A.S.M.E., 1947, vol. 69, Aug., pp. 561–568). The general requirements for materials for application in the high-temperature parts of gas turbines are outlined. The design and choice of material for specific parts, such as exhaust casings and rotor discs ,are treated in some detail.—C. O.

**Precipitation-Hardened Alloys for Gas-Turbine Service. I—Metallurgical Considerations. II—Design and Application.** H. Scott and R. B. Gordon. (Transactions of the A.S.M.E., 1947, vol. 69, Aug., pp. 583–599). A detailed account is given of the metallurgical principles involved in the development of precipitation-hardening alloys for gas turbines. The selection of the alloying metals,

heat-treatment, and the use of short-time tensile and creep-rupture tests are discussed in Part I, which also contains data on the alloys K42B, Discaloy, Refractaloy 26, and Refractaloy 70. The creep properties of these alloys are given in Part II.—C. O.

**Characteristics of Three High Temperature Alloys.** J. B. Henry, jun. (Iron Age, 1947, vol. 159, June 12, pp. 58–64). The physical properties, costs, and methods of fabrication of three alloys which have proved satisfactory in service at high temperatures are compared. The alloys are a 20% chromium, 20% nickel steel (S-588); a 20% chromium, 20% nickel, 20% cobalt steel (S-590); and the alloy S-816 containing 20% of chromium, 20% of nickel, 40% of cobalt, plus molybdenum, tungsten, cobalt, and iron.—C. O.

**Investigation of Materials for Marine Propellors.** W. C. Stewart and W. L. Williams. (Proceedings of the American Society for Testing Materials, 1946, vol. 46, pp. 836-845). A comprehensive study of the chemical and mechanical properties of 32 materials which have been used or proposed for use in marine propellers is reported. Data are also given for resistance to salt-water corrosion, salt-water cavitation, and corrosion fatigue.—C. O.

**Carbon–Molybdenum Steel for Steam Pipes.** L. Rotherham. (Metallurgia, 1947, vol. 36, July, pp. 154–156). The properties of carbon–molybdenum steel as a material for use in steam pipes are considered in relation to those of other alloy steels and carbon steels employed for this purpose. The higher creep resistance of carbon–molybdenum steel in the high steam-temperature range is advantageous, but the lower ductility necessitates care in fabrication and installation.—J. R.

**Modified Type 405 Stainless Iron—A Satisfactory Lining for Petroleum Refinery Vessels.** M. A. Scheil. (Metal Progress, 1947, vol. 52, July, pp. 91–102). Tests of the effect of quenching, welding, and aluminium content on the corrosion resistance and high temperature long-time embrittlement of "modified type" 450 stainless steel (Cr 13% max., C 0·08% max., Al 0·20–0·30%, Ti or Cb 0·02% max.) are reported. Only six instances are known of the failure of this metal in service in oil-refinery pressure vessels; five of these are shown to be because of variations from the specified chemical composition and the sixth is attributed to stress corrosion.—C. O.

**Some Notes on the Uses of Stainless Steel for Engineering Purposes.** C. H. Faris. (Journal of the Junior Institution of Engineers, 1947, vol. 57, Aug., pp. 335–340). After brief notes on the corrosion-resisting properties of stainless steel, its behaviour in hot- and cold-working operations and when welded are discussed. Milling presents no difficulties, but for tapping the hole should be drilled slightly larger than for mild steel. The shortest drills possible are recommended.—R. A. R.

**Stainless Steels for Turbine Blading.** J. H. G. Monypenny. (Transactions of the Institute of Marine Engineers, 1945, vol. 57, pp. 129–140). *See* Journ. I. and S.I., 1946, No. I, p. 14A.

**Stainless Steel in the Service of the Chemical Industry.** H. Nathorst. (Teknisk Tidskrift, 1947, vol. 77, June 14, pp. 513–517). [In Swedish]. The corrosion resistance and mechanical properties of 18/8 stainless steel with and without additions of 1·5% and 2·5% of molybdenum and of 27/5/1·5 chromium–nickel–molybdenum steel are discussed.—R. A. R.

**Nickel–Manganese–Chromium Steel Wire for Aircraft Control Cables.** H. C. Boynton. (Materials and Methods, 1947, vol. 25, Apr., pp. 91–93). The physical properties of a steel containing 0·30–0·70% of carbon, 3·50–6·00% of manganese, 11·0–14·00% of nickel, and 3·0–6·0% of chromium are tabulated. This steel is of particular use in the manufacture of aircraft control cables, as its coefficient of expansion is very similar to that of aluminium alloys.—C. O.

**Proper Selection of Steel Simplifies Deep-Drawing.** G. B. Nisbet. (Pressed Metal Institute: Materials and Methods, 1947, vol. 25, Apr., pp. 108–112). An account is given of the chemical compositions and physical properties of the steels most suitable for deep-drawing in such operations as the stamping of motor-car body parts. The elimination of stretcher strains and the choice of die material are also discussed.—C. O.

**Stainless Steels for Springs.** H. C. R. Carlson. (Product Engineering, 1947, vol. 18, May, pp. 103–106; June, pp. 153–156). Data on the composition, properties, fabrication, heat-treatment, and cost of stainless steel suitable for making springs to be used over a wide temperature range are presented and discussed.—R. A. R.

**Malleable Iron Castings—Grades, Design Data, and Applications.** J. H. Lansing. (Product Engineering, 1947, vol. 18, June, pp. 110–114). Data are given on the mechanical and physical properties of the standard grades of malleable iron and of pearlitic and alloy malleable iron, and recommendations are made for the dimensions of malleable castings (*e.g.*, the radii of fillets on ribs and sections).—C. O.

**Steel Tubes and Tubulars Suitable for Screwing to B.S. 21 Pipe Threads.** (B.S. 1387 : 1947, British Standards Institution, 1947, July)—J. P. S.

**German War List of Ferrous Materials (Kriegsliste).** (British Intelligence Objectives Sub-Committee, 1947, File No. XXXIII-59 : H.M. Stationery Office). This is a review of Part I of the German War List of Ferrous Materials in which rolled and forged steels are arranged according to chemical composition.—R. A. R.

**Metallurgical Examination of Three Japanese 75 mm. High-Explosive Shells and Carrier.** (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1437 : H.M. Stationery Office).

**Metallurgical Examination of Armour Plate from Japanese Aircraft "Frank."** (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1438 : H.M. Stationery Office).

**Metallurgical Examination of a Japanese Army 105 mm. H.E. Shell of 1938.** (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1440 : H.M. Stationery Office).

**Metallurgical Examination of Japanese 63 Kilogram Bombs, Fuzes and Gaines.** (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1442 : H.M. Stationery Office).

**Metallurgical Examination of Four Japanese 50 mm. Grenades and Six Fuzes.** (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1443 : H.M. Stationery Office).

**Metallurgical Examination of Armour Plate from Japanese Type I F "Oscar" Mark II. SE Fighter.** (British Intelligence Objectives Sub-Committee, Report No. B.I.O.S./J.A.P./P.R./1444 : H.M. Stationery Office).

**A Metallurgical Examination of Two Japanese 7·7 mm. Aircraft Machine Guns of 1938 and 1942.** (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1445 : H.M. Stationery Office).

**Metallurgical Examination of a Japanese Model 89 7·7 mm. Aircraft Machine Gun.** (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1447 : H.M. Stationery Office).

**Metallurgical Investigation of an 8 cm. Japanese Anti-Aircraft Gun.** (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1448 : H.M. Stationery Office).

**A Metallurgical Examination of a Japanese 20 mm. Aircraft Machine Gun.** (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1449 : H.M. Stationery Office).

**A Metallurgical Examination of Four Japanese 47 mm. Armour-Piercing High-Explosive Shells.** (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1450 : H.M. Stationery Office).

**Metallurgical Examination of Japanese 81 mm. Explosive Light Mortar Shell Complete with Type 93 Fuze.** (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1445 : H.M. Stationery Office).

**A Metallurgical Examination of Japanese 37 mm. Round Nose, A.P. Ammunition.** (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1473 : H.M. Stationery Office).

**Metallurgical Examination of a Japanese 50 mm. Mortar Grenade Smoke Shell and Fuse.** (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1476 : H.M. Stationery Office).

**A Chemical and Metallurgical Examination of a Section of Japanese Body Armor.** (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1477 : H.M. Stationery Office).

**Metallurgical Examination of a 6·5 mm. Japanese Light Machine Gun.** (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1478 : H.M. Stationery Office).

**Metallurgical and Chemical Examination of a Japanese Landing Gear and Wheel.** (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1479 : H.M. Stationery Office).

**Metallurgical Examination of a Japanese Sakae-12 Aircraft Engine Mount.** (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1487 : H.M. Stationery Office).

**Metallurgical Examination of a Japanese Aircraft Exhaust Stack and Collector Ring.** (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1490 : H.M. Stationery Office).

**Metallurgical Examination of Japanese Roller-Bearing Assemblies from Aircraft Engine "Zeke."** (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1441 : H.M. Stationery Office).

## METALLOGRAPHY

**Metallographic Electropolishing.** J. L. Waisman. (Metal Progress, 1947, vol. 51, Apr., pp. 606–610). A simple explanation of the mechanism of electropolishing is given, with a short account of the essential features of an electropolishing installation. The apparatus and electrolytes used by the author for the routine polishing of steels and aluminium alloys are described.—C. O.

**Electrolytic Polishing and Lapping for Mirror Finishes.** J. Mazia. (Steel, 1947, vol. 120, May 19, pp. 84–87, 126–128). A technique for the electrolytic polishing of metals is described in which the specimen (the anode) is rubbed over a "brush" consisting of a metallic core (the cathode) enveloped in a glass cloth soaked with the electrolyte.—R. A. R.

**Polishing Metallographic Specimens with Diamond Dust.** G. C. Woodside and H. H. Blackett. (Metal Progress, 1947, vol. 51, June, pp. 945–947). The technique used in polishing carbide and other very hard surfaces with diamond dust for metallographic examination is described.—C. O.

**A New Electron Microscope with Continuously Variable Magnification.** J. B. le Poole. (Philips Technical Review, 1947, vol. 9, No. 2, pp. 33–45). A simple account is given of the theory of the electron microscope, with particular reference to the focusing of electron beams by magnetic lenses. A new electron microscope now in use at the Institute of Electron Microscopy at Delft incorporates a third lens between the objective and the projector, which makes it possible to vary the magnification continuously from × 1000 to × 80,000. A fourth lens, called the diffraction lens, situated between the objective and the intermediate lens, enables the magnifications to be varied continuously between × 6000 and × 1000. The resolving power is about 25Å.—C. O.

**The Electron Microscope and Its Use in the Study of Surface Conditions.** G. Dupouy. (Commission Technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, Paris, 23–26 Oct., 1945, pp. 15–33).

**The Electron Microscope.** H. Bruck and P. Grivet. (Commission Technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, Paris, 23–26 Oct., 1945, pp. 162–176).

**Methods and Results of the Investigation of Metals with the Electron Microscope.** D. L. Ingelse. (Metalen, 1947, vol. 1, May, pp. 155–157; June, pp. 181–187; July, pp. 203–206). [In Dutch]. A method of preparing suitable replicas of etched metal surfaces for examination with the electron microscope is described. The results obtained from specimens of heat-treated steel and aluminium are compared with those obtained with the ordinary metallurgical microscope.—R. A. R.

**The Contribution of the Physics of X-Rays to Metallurgy.** P. Bastien. (Mémoires de la Société des Ingénieurs Civils de France, 1943, vol. 96, July–Sept., pp. 208–226). The author considers the applications of crystal analysis in metallurgy and the results obtained. He deals with pure metals, equilibrium diagrams, heat-treatment transformations, crystal orientation in hot- or cold-worked metals, the growth of crystals, recrystallization phenomena, and surface stresses—J. C. R.

**Radiography as a Control for Welding Joints in Pipe Lines.** R. G. Rhoades. (Welding Journal, 1947, vol. 26, June, pp. 497–498). A technique developed for the control of the quality of welds in 18-in. dia. oil pipelines is outlined. From 5% to 10% of the welds in the line, which was laid at the rate of 4000–10,000 ft./day, were tested radiographically, using a radium capsule inserted into the pipe through a $\frac{3}{4}$-in. hole and centred by a special jig. The fine-grain film was placed around the outer periphery of the $\frac{1}{4}$-in. thick wall and exposed for 12–14 min. The results were evaluated by reference to standards established from the examination of 20 pipe joints of known quality.—C. O.

**High-Temperature X-Ray Diffraction.** (Iron Age, 1947, vol. 160, July 10, pp. 51, 128). A brief description is given of an apparatus developed by the National Bureau of Standards laboratories for the examination of powder by X-ray diffraction at temperatures up to 2700° F. The equipment includes a Norelco X-ray spectrometer, in which a Geiger counter is used instead of a photographic film.—C. O.

**Industrial Application of X-Rays.** P. Bastien. (Génie Civil, 1947, vol. 124, Apr. 15, pp. 149–151). The uses of X-rays in industry are discussed with special reference to metallography. The method of applying X-rays for the detection of defects in metals is explained.—R. F. F.

**Radiographic Specifications; Their Nature, Purpose, and Current Revisions.** J. J. Pierce. (Industrial Radiography, 1947, vol. 5, Spring Issue, pp. 21–23, 50).

The development, nature, and objects of some established American radiographic-inspection specifications are discussed. The necessity for the standardization of technique and terminology, for consistency in interpretation of radiographs, and for more widespread agreements concerning specifications, is emphasized.—C.O.

**Micro-Radiography of Gray Cast-Iron.** E. I. Salkovitz, J. H. Schaum and F. W. Van Batchelder. (American Foundrymen's Association, 1947, Preprint No. 47-32). This report is a description of the micro radiographic technique by which graphite in grey cast iron may be studied with conventional X-ray equipment. Good results are obtained by using an industrial tungsten-target X-ray tube. The effects of different exposure times, photographic plates, and radiation are shown.—R. A. R.

**A General-Purpose Debye-Scherrer Camera and Its Application to Work at Low Temperatures.** W. Hume-Rothery and D. J. Strawbridge. (Journal of Scientific Instruments, 1947, vol. 24, Apr., pp. 89–91). A description is given of a Debye-Scherrer camera designed to accommodate apparatus for maintaining the specimen at high or low temperatures. A method has been devised for controlling the temperature of the specimen accurately between room temperature and −110° C. The specimen is enclosed in a chamber of still air, cooled externally by vapour from liquid oxygen conducted between a succession of concentric cellophane windows. Special provision is made to prevent deposition of ice. —C. O.

**X-Ray Apparatus for Investigations of Fine Structure Using the Geiger-Müller Tube.** O. Alvfeldt. (Teknisk Tidskrift, 1947, vol. 77, Mar. 1, pp. 217–220). [In Swedish]. A description is given of an X-ray apparatus, developed by the Naval Research Laboratory in the United States, which incorporates a Geiger-Müller counter and instruments for studying phase changes and the crystalline structure of metals.—R. A. R.

**Extinction in X-Ray Crystallography.** Kathleen Lonsdale. (Journal of the Mineralogical Society, 1947, vol. 28, Mar., pp. 14–25). The total absorption and the total scattering from a single crystal or from a crystalline powder are both affected by primary and secondary extinction, to an extent which varies with crystal texture. The dependence of each on the wavelength of X-rays, on perfect crystallite size, and on the over-all size of specimen is considered. It is concluded that secondary extinction for a fine powder is greater than that for a coarse powder and that the linear absorption coefficient measured on powdered briquettes or on metal foil is not the correct value to use in single-crystal work. Divergent-beam transmission photographs give much qualitative information about crystal texture. —C. O.

**Some Photographic Aspects of Industrial Radiography.** H. E. Seeman. (Industrial Radiography, 1947, vol. 5, Spring Issue, pp. 9–15). The action of X-rays and other radiations on photographic materials is considered from the viewpoints of the nature of the radiation and the structure of a photographic emulsion. Density characteristics, developing, fixing, and the use of lead-foil screens are also discussed.—C. O.

**Constructing a Multiple Exposure Chart for X-Rays.** (Steel, 1947, vol. 120, Apr. 28, pp. 103–104, 134). A method of preparing a sliding-scale exposure chart for X-ray and gamma-ray exposures is described.—R. A. R.

**The Fundamentals of Metallurgy.** K. G. Keeling. (Association of Engineering and Shipbuilding Draughtsmen, 1946–1947. Pamphlet). A very elementary account is given of the physical metallurgy of the common ferrous and non-ferrous metals and alloys.—C. O.

**Identification of Magnetic Phases.** Eleanor M. A. Harvey. (Overseas Engineer, 1947, vol. 20, July, pp. 385–386). A metallographic method for identifying magnetic phases in duplex microstructures, using a small electro-magnet and a colloidal iron solution, is briefly explained.—C. O.

**Metallography for the Electroplater.** A. Blazy and J. B. Mohler. (Metal Finishing, 1947, vol. 45, Apr., pp. 54–57; May, pp. 68–71). The metallographic techniques used for the examination of electroplated coatings are outlined, and the interpretation of microstructures is briefly discussed. A table of the etching reagents for the common metals and alloys is presented.—C. O.

**Study of Metallic Surfaces by Electrolytic Means. Rôle of the Beilby Layer.** A. Grumbach. (Commission Technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, Paris, 23–26 Oct., 1945, pp. 37–39).

**Beilby Layer. Comparison of Electrostatic and Electronic Proofs of Its Existence.** F. J. Taboury. (Commission Technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, Paris, 23–26 Oct., 1945, pp. 40–43).

**Surface Work-Hardening of Aluminium and Iron by Abrasion. Use of Reflected X-Rays in the Study of Surface Conditions.** J. Benard, P. Lacombe and G. Chaudron. (Commission Technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, Paris, 23–26 Oct., 1945, pp. 73–80).

**Structure of Sliding Surfaces.** G. I. Finch. (Commission Technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, Paris, 23–26 Oct., 1945, pp. 92–94).

**Microgeometry and Study of the Shapes of Surfaces. Present State of the Problem, Definitions.** P. Nicolau. (Commission Technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, Paris, 23–26 Oct., 1945, pp. 97–99).

**Some Problems Relating to the Conception of Instruments for the Study of Surfaces.** R. E. Reason. (Commission Technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, Paris, 23–26 Oct., 1945, pp. 100–103).

**Generalities on Optical Methods of Examining Surfaces. Methods Used at the Institut d'Optique.** A. Arnulf. (Commission Technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, Paris, 23–26 Oct., 1945, pp. 104–109).

**Survey of Recent Work on the Measurement of the Roughness of Surfaces.** C. Timms. (Commission Technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, Paris, 23–26 Oct., 1945, pp. 117–123).

**Comparison of the Principal Methods of Microgeometric Control.** G. Michalet. (Commission Technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, Paris, 23–26 Oct., 1945, pp. 124–134).

**Suggestions on the Use of the Correlogram for the Interpretation of Records of Surface Finish.** J. R. Womersley and M. R. Hopkins. (Commission Technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, Paris, 23–26 Oct., 1945, pp. 135–139).

**Determination of the Surface Condition of a Machined Piece by Stereoscopic Observation and Measurement of a Coefficient Relating to the Industrial Use of that Piece.** A. Mauzin. (Commission Technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, Paris, 23–26 Oct., 1945, pp. 140–142).

**Present State of Standardization and Some Methods of Control of Surface Condition in Sweden.** K. Wessel. (Commission Technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, Paris, 23–26 Oct., 1945, pp. 144–148).

**Optical Study of the Condition of Sanded Surfaces and the Devising of Tests.** F. Canac. (Commission Technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, Paris, 23–26 Oct., 1945, pp. 149–152).

**Relation between the Coefficient of Friction and Surface Condition.** A. Marcelin. (Commission Technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, Paris, 23–26 Oct., 1945, pp. 179–184).

**The Relationship of the Growth Exhibited on Nitriding to the Microstructure of the Nitrided Specimen.** L. F. Spencer. (Steel Processing, 1947, vol. 33, Apr., pp. 227–231, 239, 242, 245, 246 ; May, pp. 297–303 ; June, pp. 362–367, 369, 370, 372, 373). Investigations of the microstructure of nitrided cast irons and steels are reported. —R. A. R.

**Formation of Graphite in Cast Iron, and Malleablization of Cast Iron by Graphitization.** M. Guédras, (Revue de l'Industrie Minérale, Mémoires, 1944, Feb., pp. 47–66). This is a review of research on graphite in cast iron, and the graphitization of white cast iron to produce malleable cast iron. A bibliography is appended.—R. F. F.

**Graphite Formation in Grey Cast Iron.** H. Morrogh and W. J. Williams. (Institute of British Foundrymen, 1947, Paper No. 875 : Engineering, 1947, vol. 164, Aug. 8, pp. 141–143 ; Foundry Trade Journal, 1947, vol. 82, Aug. 21, pp. 359–363 ; Aug. 28, pp. 391–396; Sept. 4, pp. 7–12). An attempt is made to set out as many as possible of the anomalies of graphite formation which require correlation. These are discussed and their interrelations are developed to provide a basis upon which a general theory of graphite formation may be erected. Experiments on graphite formation in the analogous systems nickel–carbon and cobalt–carbon are described. Undercooling occurs in both. It was also found that spherulitic graphite nodules can be produced in cast irons without any heat-treatment under conditions predicted from the results obtained in the studies of the above systems.—R. A. R.

**Metallographic Identification of Sigma Phase in 25-20 Austenitic Alloy.** G. N. Emmanuel. (Metal Progress, 1947, vol. 52, July, pp. 78–79). Photomicrographs are presented to show the appearance of the sigma phase in 25/20 chromium–nickel steel as revealed by etching (*a*) electrolytically in oxalic acid, (*b*) in aqua regia, and (*c*) in Murakami's reagent.—C. O.

**Alpha–Gamma Transformation in Iron–Carbon Alloys.** W. J. Wrazej. (Nature, 1946, vol. 158, Aug. 31, p. 308). Based on microscopic and X-ray studies of quenched hypo- and hypereutectoid steels, it is suggested that austenite is not homogeneous but made up of three " pseudo-phases." These are designated $\gamma G$, $\gamma S$, and $\gamma E$ in accordance with the $G$, $S$, and $E$ points of the equilibrium diagram, the austenite in carbon-free iron being $\gamma G$ only, in hypo-eutectoid steels $\gamma G$ plus, $\gamma S$ and in hypereutectoid steels $\gamma S$ plus $\gamma E$. The compositions of $\gamma G$, $\gamma S$, and $\gamma E$ are stable, being made up respectively of pure face-centred cubic iron, of six face-centred cubic iron cells with one carbon atom, and of three face-centred cubic iron cells with one carbon atom. On quenching, $\gamma G$ is transformed into ferrite and $\gamma S$ into martensite, whereas $\gamma E$ is retained as austenite.—D. R. S.

**Structure of Retained Austenite in Plain Carbon Steels.** W. J. Wrazej. (Nature, 1947, vol. 160, July 19, p. 93). Intensity curves of the 200, 220, and 311 lines of retained austenite in quenched samples of steel with 0·75%, 0·89%, and 1·20% of carbon are reproduced. The shape of the curves indicates that the retained austenite is not face-centred cubic but face-centred tetragonally distorted, the tetragonality decreasing with increasing amount of retained austenite. By quenching iron-carbon alloys, the amounts of the austenitic pseudophases $\gamma G$, $\gamma S$, and $\gamma E$ (*see* preceeding abstract) can be revealed, the grains being made up of martensite and austenite derived from $\gamma S$ and $\gamma E$ respectively. The presence of martensite and austenite in phases differing in structure and parameter and linked closely together causes a tetragonal distortion of each, martensite being distorted so that $c/a > 1$, and austenite so that $c/a < 1$.—D. R. S.

**Microstructure and Structural Diagrams for Fe–Ni–Cr Alloys.** A. de S. Brasunas and J. T. Gow. (Metal Progress, 1947, vol. 51, May, pp. 777–780). The influence of variations in chromium content from 11% to 31% and of up to 68% of nickel on the microstructures of iron–nickel–chromium alloys containing 0·4% of carbon, 1·2% of silicon, and 0·8% of manganese, is shown in a series of photomicrographs. Structural diagrams constructed from these photomicrographs and similar ones for other alloys, and from magnetic-permeability data, are reproduced.—C. O.

**The Effect of Changes of Condition of Carbides on Some Properties of Steel.** J. B. Austin. (Campbell Memorial Lecture : Metal Progress, 1946, vol. 50, Dec., pp. 1191–1195 ; Industrial Heating, 1947, vol. 14, Mar., pp. 398–408). Possible variations in the composition of cementite due to variation in the ratio of the number of metal atoms to the number of carbon atoms, and the effects of such variations on the properties of steel are discussed.—R. A. R.

**A New Method for Making Rapid and Accurate Estimates of Grain Size.** F. C. Hull. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2160 : Metals Technology, 1947, vol. 14, June). A description is given of a method of estimating grain-size by comparing an image of the sample on a ground glass plate with a transparent standard viewed by transmitted light. The objective and eyepiece of the magnifying system are so chosen that when the size of the sample image has been altered by varying the bellows extension to give the same number of grains per unit area as the standard, a correction factor can be measured off to give the A.S.T.M. grain-size.—C. O.

**Microstructure of Silvery Pig Iron.** R. Schneidewind and C. Harmon. (American Foundrymen's Association, 1947, Preprint No. 47-31). Comparatively little has been published on the microstructure of silvery pig iron and efforts to study it required the development of new etching agents. The structure is a matrix of σ-silicoferrite with large hypereutectic graphite flakes and small eutectic flakes. The grain shape varies, the crystals being equi-axed or elongated. X-ray diffraction methods indicate that the sillicoferrites in the silvery irons studied were identical. Steadite was found in all samples.—R. A. R.

**Austenite Grain Size in Cast Steels.** M. F. Hawkes. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2170: Metals Technology, 1947, vol. 14, June). To determine the suitability of the various established methods of measuring austenitic grain-size for determining the grain-size of cast steel, in the as-cast and heat-treated states, tests were made on 50 commercial steels of varying compositions. The martensitic-etch method was found to be satisfactory and reliable for nearly all carbon and alloy steels and is

recommended as a routine laboratory test. Fine-grained structures resistant to grain growth were obtained as easily in cast steels as in wrought S.A.E. steels. Although the austenitic grain-size of as-cast steels is very large, this structure appears to have little influence on the grain-size of the steel after heat-treatments.—C. O.

**The Electron Emission of Crystalline Metal Surfaces and Its Relation to the Laws of Crystal Structure.** I. N. Stranski and R. Suhrmann. (British Intelligence Objectives Sub-Committee, 1947, Final Report Nos. 1030 and 1031 : H.M. Stationery Office). [In German]. In Part I the results obtained from electro-emission research and from crystallographic research on single tungsten crystals are critically compared. In Part II the geometric and energy laws applicable to crystals by which foreign atoms are absorbed are developed on the basis of experimental work on the electron-emission of caesium- and barium-coated tungsten crystals.—R. A. R.

**Identification of CaO–MgO Orthosilicate Crystals, Including Merwinite ($3CaO.MgO.2SiO_2$), through the Use of Etched Polished Sections.** R. B. Snow. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2167 : Metals Technology, 1947, vol. 14, June). A procedure has been developed for the identification of the principal crystalline constituents of basic open-hearth slags and furnace bottoms by the examination of etched polished sections without the use of a petrographic microscope.—C. O.

**Experimental Evidence of the Viscous Behaviour of Grain Boundaries in Metals.** T.-S. Ké. (Physical Review, Second Series, 1947, vol. 71, Apr. 15, pp. 533–546). The behaviour of grain boundaries was studied by measuring four types of so-called "anelastic" effects at very low stress levels, *viz.* : The internal friction at low frequencies, the variation of the dynamic rigidity with temperature, the creep under constant stress, and the stress relaxation at constant strain. A simple torsion-measuring apparatus was designed for the experiments. Anelastic effects were observed on polycrystalline specimens but not on single crystals, the results obtained being in accordance with the assumption that the grain boundaries behave in a viscous manner. Although the experiments were carried out on aluminium and magnesium only, the results are stated to be applicable to all metals.—D. R. S.

**The Application of Single Crystals to the Study of Tempered Martensite.** G. Kurdjumov and L. Lyssak. (Journal of the Iron and Steel Institute, 1947, vol. 156, May, pp. 29–36). The orientation relationships between martensite and austenite lattices in quenched steel enable the reflections (002) and (200), (020) of the martensite lattice to be obtained on separate films, using single-crystal specimens. Thus it becomes possible to measure the $a$ and $c$ constants of the tetragonal lattice of martensite when the axial ratio $c : a$ is small and its structure is homogeneous.

In this paper the structure of tempered martensite has been examined. The X-ray camera was provided with a special arrangement in order to increase the accuracy in measuring the lattice constants. It has been established by direct measurements of the constants $a$ and $c$ that martensite tempered at 125–150° C. has a tetragonal lattice with an axial ratio of about 1·012–1·013. The tetragonal lattice of tempered martensite has been observed after tempering at temperatures up to 250–300° C. Thus the product of the so-called "first transformation" in tempering, in other words the tempered martensite, represents the partly decomposed solid solution of the carbon in α iron. After tempering at 150° C. a certain quantity of carbon, 0·3–0·5%, remains dissolved in the solid solution. It decreases as the tempering temperature rises and after tempering at temperatures above 300° C., less than 0·1% of carbon remains in the solution. The kinetics of martensite decomposition have the character of a reaction of the first order.

## CORROSION

**Must Iron Rust?** (Tin and Its Uses, 1947, No. 18, July, pp. 5–8). Experimental work does not support the contention that phosphatized zinc is a sound base for paint and it is suggested that a thin coating of tin is more suitable. This is supported by corrosion tests on steel, under-coated with tin and painted.—M. A. V.

**The Corrosion of Metals. Part I—Factors Affecting Corrosion. Part II—Types of Corrosion. Part III—Corrosion Testing. Part IV—The Corrosion of Iron and Steel. Part V—The Corrosion of Tinplate. Part VI—The Corrosion of Copper and Its Alloys. Part VII—Zinc and Its Alloys.** (Sheet Metal Industries, 1946, vol. 23, Feb., pp. 309–320, 334 ; Mar., pp. 527–532 ; Apr., pp. 731–735, 736 ; May, pp. 933–940, 954 ; June, pp. 1145–1146, 1159 ; July, pp. 1333–1342, 1350 ; Sept., pp. 1756–1757, 1768 ; Oct., pp. 1951–1960 ; Nov., pp. 2159–2164 ; 1947, vol. 24, Jan., pp. 145–153 ; Apr., pp. 801–806). The theory of corrosion is discussed in the most general terms, but the mathematical aspect is not dealt with. Particular consideration is given to the design of structures in relation to corrosion prevention, corrosion testing and the interpretation of test data, and to the galvanic effect of metals in contact with each other. Problems connected with the corrosion of light metals and their alloys are also dealt with.—R. A. R.

**The Formation of Rust and Other Products of Corrosion.** W. Wiederholt. (Technik, 1947, vol. 2, May, pp. 217–224). The theory of the corrosion and scaling of iron and steel, and of the corrosion of the common non-ferrous metals is explained. The properties of the corrosion products and methods of removing them are discussed.—R. A. R.

**The Welding of Chemical Plant.** B. Goedhuis. (Nederlandse Vereniging voor Lastechniek, Lassymposium, 1947, June, pp. 51–78). [In Dutch.] A brief summary is given of the theory of corrosion and the corrosion resistance of welds in unalloyed steel, stainless steel, and non-ferrous metals is discussed. Finally, the strength of stainless steel at various temperatures and the effect of this on the design of chemical plant are dealt with.—R. A. R.

**Nitrogen-Containing Organic Inhibitors of Corrosion.** Shih-Jen Ch'Iao and C. A. Mann. (Industrial and Engineering Chemistry, 1947, vol. 39, July, pp. 910–919). The difference in functions between organic inhibitors and cathodic inorganic inhibitors is pointed out. An apparatus for measuring cathode potential in the presence of various inhibitors is described, and the application of cathode-potential measurements to the determination of inhibition efficiencies is considered. The absorption of nitrogen-containing organic inhibitors seems to follow Traube's rule, although it is cathodic in nature. The relation between the angle of inclination to the surface of long-chain mono-aliphatic amines and inhibitor concentration, and the application of Langmuir's equation for monomolecular absorption are discussed.—C. O.

**Activation of Passive Iron.** W. H. Cone and D. H. Anderson. (Corrosion and Material Protection, 1947, vol. 4, July-Aug., pp. 21–23). Short accounts are given of experiments made to determine the nature of the

passivity of iron in nitric and chromic acid solutions. It is considered that passivation can be caused by an adsorbed layer of gas ; if this is disturbed in conditions not leading to its reformation, the iron will become and remain active.—C. O.

**Resistance of Metals and Alloys to Corrosion.** U. R. Evans. (Commission Technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, Paris, 23–26 Oct., 1945, pp. 233–234).

**Influence of the Surface Condition on the Dry Oxidation of Nickel–Chromium Austenites and of the Manner of Finishing of the Specimens on the Mechanical Hysteresis of Steels.** P. Chevenard and X. Waché. (Commission Technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, 23–26 Oct., 1945, pp. 237–241).

**Epitaxy in the Phenomena of Corrosion.** M. Capdecomme. (Commission Technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, Paris, 23–26 Oct., 1945, pp. 247–249). The effect of the crystalline structure of the base metal upon that of the metal deposited upon it, and the relation of this to corrosion resistance are discussed.—R. A. R.

**Corrosion, Passivity and Passivation from the Thermodynamic Point of View.** M. Pourbaix. (Commission Technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, Paris, 23–26 Oct., 1945, pp. 251–265).

**The Overvoltage of Hydrogen, in Particular on Nickel, Tantalum and Niobium.** Eva Palmaer. (Commission Technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, Paris, 23–26 Oct., 1945, pp. 266–271).

**Researches on Corrosion Carried out in Sweden during the War.** Eva Palmaer. (Commission Technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, Paris, 23–26 Oct., 1945, pp. 272–273).

**Insulation of Dissimilar Metal Faying Surfaces.** B. W. Floersch. (Corrosion and Material Protection, 1947, vol. 4, July–Aug., pp. 16–18). Tests made to determine the insulation necessary to prevent galvanic corrosion between various pairs of dissimilar metals in contact are briefly described. Sheets of Dural and cadmium-plated steel, magnesium and Alclad, and magnesium and stainless steel, were treated with zinc chromate primer and tested in salt-spray cabinets.—C. O.

**Anodic Behaviour of Mild Steel in Strongly Alkaline Solutions.** C. D. Weir. (Nature, 1947, vol. 160, Aug. 23, p. 259). A short account is given of experiments on the effect of concentration and time on the critical current density for the anodic polarization of mild steel in aqueous hydroxide solution.—C. O.

**Testing Acid-Resisting Steels for their Resistance to Intercrystalline Corrosion.** S. Plankensteiner. (Metallurgia, 1947, vol. 36, July, pp. 145–148). Intercrystalline corrosion and measures for its prevention are briefly discussed, and an account is given of practical tests carried out on austenitic chromium–nickel and chromium–nickel–molybdenum steels with the object of determining their resistance to this type of corrosion. The development and application of a new testing liquid are described, and it is claimed that its use gives clearer and more accurate results than those obtained with the generally employed solution of copper sulphate in sulphuric acid.—J. R.

**The Scaling Behaviour of High-Strength Heat-Resisting Steels in Air and Combustion Gases.** W. Stauffer and H. Kleiber. (Journal of the Iron and Steel Institute, 1947, vol. 156, June, pp. 181–188). In the gas turbine, as in any heat engine, the effective work is brought about by the combustion of fuel. The hot structural components are thus exposed not only to the mechanical stresses due to pressure, loads, and rotation, but also to the chemical attack of the combustion products. The investigation of the chemical resistance of the steels must be carried out in co-operation with the designer of the gas turbine, so as to co-ordinate the various requirements.

A new apparatus for carrying out scaling tests in gas mixtures, and the experimental technique are described. This apparatus was used for studying the effect of synthetic combustion gases with low, medium, and high sulphur contents on martensite, ferritic, and austenitic high-strength heat-resistant steels. The results obtained, together with those of scaling tests carried out on the same steels in air, are presented in the form of curves.

**Resistance of Iron–Nickel–Chromium Alloys to Corrosion in Air at 1600° to 2200° F.** A. de S. Brasunas, J. T. Gow, and O. E. Harder. (Symposium on Materials for Gas Turbines, 1946, June, pp. 129–152). The resistance of iron–nickel–chromium alloys to corrosion in air saturated with water vapour at 90° F., was tested for 100 and 1000-hr. periods at 1600°, 1800°, 2000°, and 2200° F. Three-dimensional diagrams are presented showing the chromium and nickel contents at which the corrosion in inches/year remains the same. The trends indicated by 100-hr. tests were, in general, confirmed by the 1000-hr. tests.—R. A. R.

**Estimation of Scaling Resistance.** H. S. Avery. (Alloy Casting Bulletin, 1947, May, pp. 9–12). A series of nomographs, prepared on the basis of experimental data, is given to enable designers to estimate the corrosion of iron–nickel–chromium alloys by hot gases. They relate to air at 1600° F., 1800° F., and 2000° F. and flue gas at 1800° F., oxidizing or reducing, containing 5 or 10 grains of sulphur per 100 cu. ft.—M. A. V.

**Water Purification and Corrosion Control.** C. E. Trowbridge. (Journal of the American Water Works Association, 1946, vol. 38, Dec., pp. 1380–1382). The mechanism of the corrosion of metals by water, and of its prevention, is outlined. The addition of lime to the water before entering the filter bed is recommended ; it should be sufficient to provide a filtered water with a *p*H of about 7·5.—M. A. V.

**Feed-Water—Independent De-Aerating Plant for Steel Works.** (Iron and Steel, 1947, vol. 20, Feb., p. 54). An atomizing spray de-aerator which leaves no measurable trace of oxygen in the feed-water as it enters the boiler feed pump is described.—R. A. R.

**The Problem of the Corrosion of Arens Tubes Centrifugally Cast at the Works of Louis de Roll, Choindez.** (Von Roll Mitteilungen, 1947, vol. 6, June). An extensive investigation of the causes of the corrosion of centrifugally cast iron pipes (by the Arens process) of Zürich water-supply system is reported. Dangerous corrosion penetrating the wall had occurred at cracks in an outer layer of magnetite where the bare metal was exposed to oxygen in the moist soil. A laboratory test simulating these conditions was devised. The pipes could be made resistant to this corrosion by heat-treatment in a reducing atmosphere.—R. A. R.

**Cast Alloys Stabilized with Columbiun or Titanium. The Influence on Corrosion Resistance of Columbium and Titanium Additions to CF Type Alloys.** E. A. Schoeffer. (Alloy Casting Bulletin, 1947, May, pp. 1–7). Tests were carried out to determine whether chromium carbide formation, and consequent lessened corrosion resistance could be prevented in CF type cast alloys (Cr 17·8–20%, Ni 8·7–9·4%) by the addition of columbium or titanium, as in 18/8 wrought alloys. Boiling 65% nitric acid was

used as the corroding agent, and penetration rates measured. Titanium additions, although preventing intergranular attack led to excessive general corrosion after exposure to 1200° F. Columbium was much better in this respect, and further improvements were achieved, especially with low-chromium alloys, by stabilizing at 1600° F., in place of the usual 2075° F. quench-anneal. Columbium, however, was not satisfactory with alloys containing molybdenum, which again had poor corrosion resistance after exposure at 1200° F.—M. A. V.

**Nature and Mechanism of Passivity of 18–8 Stainless Steel.** M. G. Fontana and F. H. Beck. (Metal Progress, 1947, vol. 51, June, pp. 939–944). Tests on 18–8s steel (18–20% chromium, 8–11% nickel, 0·08% max. carbon) which are described showed that a passivated surface becomes active after exposure in a vacuum and passive again after exposure in air. Electron diffraction gives no indication of oxide layers on the passivated surfaces. The authors conclude that the passivation is caused by a physically absorbed layer of gas molecules.—C. O.

**Graphitic Corrosion of Cast Iron.** L. M. Leedom. (Journal of the American Water Works Association, 1946, vol. 38, Dec., pp. 1392–1397). The nature of cast iron and the mechanism of graphitic corrosion are discussed generally and the particular case of the failure of cast-iron valves in the Newark, New Jersey, water supply system is described. It is suggested that this could have been avoided by the use of alloy cast iron. Modifications to A.S.T.M. specification A 126–42 are proposed.—M. A. V.

**Corrosion Testing—Evaluation of Metals for Process Equipment.** A. Wachter and R. S. Treseder. (Chemical Engineering Progress, 1947, vol. 43, June, pp. 315–326). The considerations involved in the planning, conducting, and interpreting of tests of the serviceability of metals in specific applications in chemical engineering are discussed at length.—C. O.

**Common Industrial Electroplates—I. Ferrous Base Metals.** P. W. Prouty. (Product Engineering, 1947, vol. 18, Mar., pp. 139–142). In a very general account of electroplated coatings on steel a comparison is made between the corrosion-resisting properties of zinc and cadmium, and the uses of non-ferrous coatings of nickel, chromium, copper, and tin are discussed.—C. O.

**Application of Metallic Coatings.** R. Mansell. (Metal Finishing, 1947, vol. 45, May, pp. 62–65; June, pp. 91–94). A survey is made of corrosion, cleaning and pickling, polishing methods, and electrodeposition processes in relation to metallic coatings.—C. O.

**Rating Exposure Test Panels of Decorative Electrodeposited Cathodic Coatings.** W. A. Wesley. (American Society for Testing Materials, 1947, Preprint No. 38). A system for evaluating the results of outdoor atmospheric exposure tests of chromium-plate decorative finishes on nickel or copper–nickel undercoats has been devised. It is considered that appearance should be the sole criterion of merit, and a set of graphical reference standards has been designed by means of which a coating can be assigned a numerical rating according to the number of defective spots on a panel 4 × 6 in. The paper concludes with a discussion of the interpretation of inspection data.—C. O.

**Inspection of Exposure Tests Panels with Nondecorative Electrodeposited Cathodic Coatings.** H. A. Pray. (American Society for Testing Materials, 1947, Preprint No. 39). The function and manner of deterioration of purely protective electrodeposited cathodic coatings are discussed. The common methods of evaluating the protection afforded by such coatings are summarized, with particular reference to the methods used for testing electrodeposited lead by Sub-Committee II on Performance Tests of A.S.T.M. Committee B-8 on Electrodeposited Metallic Coatings.—C. O.

**Inspection of Exposure Test Panels with Anodic Electrodeposited Coatings.** G. Soderberg. (American Society for Testing Materials, 1947, Preprint No. 40). Methods for evaluating the protection afforded by anodic electrodeposited coatings on steel test panels exposed out-of-doors are described. With zinc and cadmium plating corrosion takes place in two stages; during the first stage the number of rust spots may be counted, and during the second the area of rusting may be estimated by the use of a ruled plastic grid.—C. O.

**The Use of Metallic Pigments in the Preparation of Protective Paints.** J. E. O. Mayne. (Journal of the Society of Chemical Industry, 1947, vol. 66, Mar., pp. 93–95). In connection with some researches carried out for the Corrosion Committee of the Iron and Steel Institute, a number of metallic pigments were examined with the object of preparing paints capable of protecting steel cathodically. For this to occur two conditions must be fulfilled: (1) The metallic pigment must be of a metal less noble than iron; and (2) the pigment particles must be in metallic contact with each other and with the coated steel. The first of these conditions is fulfilled by aluminium powder, magnesium powder, and zinc dust; but, as shown by conductivity measurements on dried paint films and by electrode potential measurements, only zinc dust satisfies the second condition. —D. R. S.

**Principles of Immersion and Humidity Testing of Metal Protective Paints.** A. C. Elm. (American Society for Testing Materials Bulletin, 1946, Oct., pp. 9–13). The principles which underly the development and selection of immersion and humidity tests of the value of paints as protection for metal surfaces are discussed. —C. O.

**Vitreous Enamelling of Chemical Plant.** J. D. Currie. (Institute of British Foundrymen: Foundry Trade Journal, 1947, vol. 81, Apr. 17, pp. 305–311; Apr. 24, pp. 329–333). The advantages of vitreous enamelling for the lining of vessels and fittings made of mild steel and cast iron and used in processes involving corrosion, erosion, violent chemical reaction, heat, etc., are discussed. Various applications are described, and methods of testing are enumerated.—J. R.

**Protective Coatings Under Test.** (Chemical Engineering, 1947, vol. 54, May, pp. 154–155). A short account is given of exposure tests of protective paints now being made by the Dow Chemical Company at Freeport, Texas, where the atmospheric conditions are particularly severe because of the climate and industries.—C. O.

**Tuberculation Measurements as an Index of Corrosion and Corrosion Control.** E. W. Barbee. (Journal of the American Water Works Association, 1947, vol. 39, Mar., pp. 220-230). Tests were carried out to determine the relative corrosiveness of San Francisco waters drawn from three different sources. Immersion tests were made, and also "head loss" measurements, in which the amount of tuberculation is estimated as the increased head necessary to pass a calibrated quantity of water through the pipe under test. Sodium pyrophosphate and sodium hexametaphosphate, in concentrations of 1 p.p.m., gave comparable performances as inhibitors.—M. A. V.

**Cathodic Protection of Steel Tank Bottoms by the Use of Magnesium Anodes.** J. R. James and R. L. Featherly. (American Institute of Mining and Metallurgical Engineers, 1947, Technical Publication No. 2202: Petroleum Technology, 1947, vol. 10, May).

Experience with magnesium anodes for the protection of oil storage tanks is reported. Data are given on potential and current measurements made on a very large tank with twelve 60-lb. anodes set around it. The annual cost of protection is estimated to be less than 1% of that of replacing the tank bottoms.—C. O.

**Cathodic Protection of Pipelines.** H. Seymour. (Mining Journal, 1947, vol. 76, June, pp. 339–340). The use of magnesium alloy anodes for the cathodic protection of pipelines is noted. The composition of the alloy is given.—R. E.

**Protection of Return Mains from Corrosion.** J. Mikula. (National District Heating Society : Industrial Heating Engineer, 1947, vol. 9, May, pp. 91–92, 96). An account is given of the efforts made to combat corrosion in the return pipes of a district-heating system in Prague. The most successful measure adopted has been the use of deoxidizing filters of steel wool, which reduce the oxygen content of the condensate below 0·1 mg./l.—C. O.

**Materials and Finishes for Tropical Service.** C. D. Cook and C. Merritt, jun. (Materials and Methods, 1947, vol. 25, May, pp. 77–80). The results of salt-spray and humidity tests of the corrosion resistance of ferrous and non-ferrous metals treated in various ways for service in electrical instruments under tropical conditions are tabulated.—C. O.

**Corrosion Protection of Japanese Ordance.** (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1463 : H.M. Stationery Office). Two types of coating were found on Japanese ordnance, (*a*) the oxide type giving little protection against corrosion, and (*b*) an alkyd-resin coating containing lamp-black pigment, which was applied over a surface prepared by a process similar to Parkerizing. Coating (*b*) offered lasting protection under salt-spray and humid conditions.—R. A. R.

## ANALYSIS

**Interpretation of Raw Materials Analysis.** J. Kalté. (Revue de l'Industrie Minérale, Mémoires, 1944, Sept., pp. 389–394). The results of analysis of raw materials, carried out by a steelworks laboratory, should give the composition in terms, not only of the constituent elements, but also of the compounds in which they occur. Examples of these analyses are given.—R. F. F.

**The Determination of Moisture in Coal.** R. Belcher and C. E. Spooner. (Fuel, 1947, vol. 26, May–June, pp. 55–56). A rapid direct method for the determination of moisture in coal is described. Air is drawn through a drying train, over a weighed coal sample, and through an Anhydrone absorber at the rate of 100 ml./min. for 15 min. Only two weighings are necessary—one of the sample and one of the absorber.—C. O.

**An Improved Apparatus for the Determination of Water in Oils and Fuels.** W. G. Marskell and J. E. Rayner. (Fuel, 1947, vol. 26, Mar.-Apr., pp. 49–50). A modification of the conventional apparatus used for estimating the amount of water in oils is illustrated. The mixed vapours from the distillation are carried to the top of the condenser so that the vapour column moves downwards, the higher-boiling-point fraction washing down the lower-boiling-point fraction which condenses lower down the tube, thus eliminating the ring of water droplets which in the older apparatus formed in the condenser.—C. O.

**Modern Methods of Gas Analysis. Part I—Importance of Accurate Analysis, Types of Gases and Collection of Samples. Part II—The Orsat Gas Analysis Apparatus. Part III—Analysis of Blast-Furnace Gas. Part IV—The Ambler Portable Apparatus. Part V—The Bone and Wheeler Apparatus.** W. D. Vint. (Metallurgia, 1947, vol. 35, Jan., pp. 153–155 ; Mar., pp. 255–257 ; Apr., pp. 294–296 ; vol. 36, May. pp. 47–50 ; July, pp. 157–159).

**Evaluating Pickling Acid Inhibitors.** E. L. Colichman, R. C. Thielke, and B. J. Cotey. (Iron Age, 1947, vol. 159, Apr. 24, pp. 55–57). Details are given of a colorimetric method of determining the iron concentration in inhibited acid solutions to measure the value of the inhibitor.—C. O.

**Analysis of Waste Pickle Liquor.** R. D. Hoak. (Iron Age, 1947, vol. 160, July 3, pp. 55–57). Standard methods for estimating ferrous and ferric ion concentration, free acid, manganese, zinc, and ferrous sulphate in waste sulphuric acid pickle liquors are outlined.—C. O.

**Hot Dip Galvanizing.** F. F. Pollak and E. F. Pellowe. (Metal Industry, 1947, vol. 71, Aug. 22, pp. 143–145). Operating details are given for routine methods of analysis of galvanizing liquors. These include the estimation of acidity and iron content of sulphuric acid pickle liquor and of the hot wash, and the analysis of the flux and etching solutions.—M. A. V.

**Simple Methods of Identifying Metallic Materials in Buried Debris.** R. von Have. (Technik, 1947, vol. 2, May, pp. 227–231).

**Spot Tests for Steels.** L. M. Kulberg. (Zavodskaya Laboratoriya : Iron and Steel, 1947, vol. 20, June, pp. 319–320). A description is given of microchemical spot-test methods for the detection of chromium, molybdenum, aluminium, nickel, vanadium, and tungsten in steels. —J. R.

**Zirconium Determination in Presence of Interfering Elements.** C. A. Kumins. (Analytical Chemistry, 1947, vol. 19, June, pp. 376–377). A method of determining zirconium by precipitation from hydrochloric acid solution with the specific reagent mandelic acid ($C_6H_5CHOHCOOH$) is described.—C. O.

**2,2′-Bipyridine Ferrous Complex Iron as Indicator in the Determination of Iron.** F. W. Cagle, jun., and G. F. Smith. (Analytical Chemistry, 1947, vol. 19, June, pp. 384–385). The preparation and use of the 2,2′-bipyridine ferrous complex as an oxidation-reduction indicator in the determination of iron in sulphuric acid solution employing the sulphato-cerate iron as oxidant are described.—C. O.

**Determination of Carbon in Low-Carbon Steel.** C. E. Nesbitt and J. Henderson. (Analytical Chemistry, 1947, vol. 19, June, pp. 401–404). An apparatus and procedure for estimating the carbon content of plain and alloyed steels containing up to 0·05% of carbon are described. A 2-g. sample is burned in a stream of purified oxygen and the carbon dioxide evolved is collected in a specially designed absorber containing sodium hydroxide solution. The carbon dioxide evolved when this solution is subsequently acidified under low pressure is measured. The determination takes about 1 hr., and the accuracy is claimed to be ± 0·0003%.—C. O.

**Determination of Oxygen in Steel by the Vacuum Fusion Method.** L. Alexander, W. M. Murray, and S. E. Q. Ashley. (Analytical Chemistry, 1947, vol. 19, June, pp. 417-422). A simplified apparatus and a modified technique for the determination of oxygen in steel by the vacuum fusion method are described. Relatively continuous operation is achieved, with a consequent saving in analysis time. The measurement of the oxygen and hydrogen contents of surface films is discussed.—C. O.

**The Determination of Silicon and Silica by the Gelatine Method.** E. Hammarberg. (Jernkontorets Annaler, 1947, vol. 131, No. 6, pp. 199–211). [In Swedish].

Experiments with the gelatine method (precipitating silica in an acid solution by the addition of gelatine) for determining silicon in pig iron, steel, and some ferro-alloys, as well as silica in silicates, have shown that the results are just as accurate as those obtained by the usual dehydration methods. The time necessary by the gelatine method, when the sample is readily soluble in acids, is about 30–40 min., not including the time for volatilization of the silica with hydrofluoric acid which is, however, unnecessary in most cases.—R. A. R.

**Colorimetric Method for the Determination of Cobalt in Stainless Steel.** H. M. Putsché and W. F. Malooly. (Analytical Chemistry, 1947, vol. 19, Apr., pp. 236–238). A colorimetric method is described for the determination of cobalt in stainless steel employing Vogel's reaction. The steel is obtained in a slightly acid medium and a single zinc oxide separation is made. An aliquot portion of the solution is reduced with sulphurous acid, and a strong sodium thiocyanate solution is added. After dilution to a definite volume, a measured amount of acetone is added, and the intensity of the blue complex, $Na_2Co\ (SCN)_4$, is measured by means of a photo-electric colorimeter. The method is applicable to all cobalt-bearing steels as well as to numerous other alloys.—R. A. R.

**The Microchemical Determination of Molybdenum in Steel.** J. E. Wells and R. Pemberton. (Analyst, 1947, vol. 72, May 1, pp. 185–188). A colorimetric method using toluene/3:4-dithiol in acid solution as reagent is described for the determination of molybdenum in steel. Steel samples of only a few milligrammes are required and other alloying elements, including tungsten, do not interfere.—D. R. S.

**A Method for the Determination of Tungsten in Steel, Using Toluene/3:4-Dithiol. The Removal of Molybdenum Interference by Selective Extraction.** B. Bagshawe and R. J. Truman. (Analyst, 1947, vol. 72, May 1, pp. 189–193). A method for the absorptiometric determination of tungsten in steel by means of toluene/3:4-dithiol is described. Interference due to the complex formed by molybdenum with this reagent is prevented by allowing this complex to be formed first in cold dilute acid solution and removing it by extraction with amyl acetate. The corresponding tungsten-dithiol complex is subsequently developed in hot concentrated acid solution. The method is applicable to practically all types of alloy steel.—D. R. S.

**Colorimetric Determination of Phosphorus in Steel.** U. T. Hill. (Analytical Chemistry, 1947, vol. 19, May 21, pp. 318–319). Some modifications of the colorimetric vanadate-molybdate method for the determination of phosphorus in steel are suggested, in particular the replacement of ammonium vanadate and molybdate by the corresponding sodium salts.—D. R. S.

**Examination of Absolute and Comparative Methods of Polarographic Analysis.** J. K. Taylor. (Analytical Chemistry, 1947, vol. 19, June, pp. 368–372). The principles of the absolute and comparative methods of polarographic analysis of solutions are explained, and the advantages and limitations of several different techniques are discussed. Comparative methods minimize many experimental uncertainties but require extensive calibration. Calibration is almost eliminated in the absolute method, but it is necessary for the experimental conditions to correspond to the boundary conditions for which the basic Ilkovič equation was derived.—C. O.

**The Direct Reading of Spectral-Line Intensities.** J. H. Oldfield. (Journal of the Iron and Steel Institute, 1947, vol. 156, May, pp. 78–80). In spectrographic analysis direct-reading methods employ a photo-tube instead of a photographic plate for recording spectral-line intensities. The line may be scanned by a moving tube, or the tube positioned behind an exit slit. Counters, or condensers charged by the photo-currents, are used to measure the light intensity, a comparison being made between a standard line and a line of the element being determined. Increased sensitivity can be obtained by amplifying devices, and intensity ratios of a high order can be measured. A commercial model, the Quantometer, consists of source, dispersing, and recording units operating as one instrument. It is claimed that the method is likely to find its greatest use in industrial control processes.

**An Investigation of Photographic Plates for Spectrum Analysis.** P. Spiegelberg. (Jernkontorets Annaler, 1947, vol. 131, No. 5, pp. 181–191). [In Swedish]. The contrast and the root-mean-square (R.M.S.) deviation from the average density due to grain have been determined for the following plates used in spectrum analysis; Ilford Process, Ilford Chromatic, Ilford Thin-Film Half-Tone, Ilford Ordinary, Kodak Spectrum Analysis No. 1 and No. 2, Gevaert Superchromosa, and Agfa Spektral Blau Hart. A formula is given for computing the R.M.S. deviation due to plate grain from the average concentration obtained by spectrochemical analysis. Measurements of contrast were made for wavelengths in the 2800–4300Å range. The density fluctuations due to grain are independent of the wavelength. The R.M.S. deviations are inversely proportional to the square root of the photometered area. The fixing time and the relative sensitivity of the above materials have been determined.—R. A. R.

**Setting Up for Spectrographic Analysis.** P. J. Gruszecki. (Iron Age, 1947, vol. 159, Apr. 17, pp. 44–46). A short account is given of the equipment and technique used in the spectrographic analysis of steel and cast-iron components, both rough and finished, in an American engineering works.—C. O.

**The Economic Significance of Direct Reading Spectrochemical Analysis.** M. F. Hasler. (Iron Age, 1947, vol. 160, July 14, pp. 71–73). The savings which can be effected by the use of direct-reading spectrographic analysis for determining the composition of molten metal before tapping are discussed.—C. O.

## MISCELLANEOUS

**Fulmer Research Institute.** (Engineer, 1947, vol. 184, July 11, pp. 37–39). A description is given of the Fulmer Research Institute which was recently opened near Slough. The Institute was founded to provide a research centre where firms can use first-class facilities, backed by the services of a team of experienced scientists. The results of the research work remain the sole property of the firm. Problems relating to physical metallurgy, metal purification, the application of thermodynamics to industrial metallurgy, and the development of new casting processes are among those being studied.—R. A. R.

**Metallurgical Research in Germany since the War.** M. Hansen. (Journal of the Iron and Steel Institute, 1947, vol. 156, July, p. 370). This brief review of the extent to which the various institutions for metallurgical research in Germany have been able to resume their activities since 1945 indicates that very little work can now be carried on because of damage to buildings, loss of equipment, and dismissal of heads of departments.—R. A. R.

**Metallurgical Research and Testing Laboratories in the Stuttgart Area.** (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 720 : H.M. Stationery Office). Reports are presented on research work which has been carried out during the 1939–1945 period at a number of laboratories in the Stuttgart area. These reports cover fundamental research and research on non-ferrous metals.—R. A. R.

**Central Research Laboratory at Winterthur.** (Engineer, 1947, vol. 183, June 20, pp. 537–539). A general description is given of the research laboratories of Sulzer Brothers, Ltd., Winterthur, Switzerland, which were opened in 1945.—C. O.

**Research and Development in Progress at the Louis de Roll Iron Works, Limited.** (Iron and Coal Trades Review, 1947, vol. 154, June 20, pp. 1201–1203). The research work in progress at the Louis de Roll Iron Works, mainly at the new laboratories at Klus, includes the determination of the dynamic physical properties of grey cast iron, the effect of dissolved gases in cast iron, and the development of new corrosion-resistant alloys, heat-resistant steels, wear-resistant alloys, and highly magnetic cast steels.—C. O.

**Federal Materials Testing and Research Institute, Zürich.** M. G. Ros. (Iron and Coal Trades Review, 1947, vol. 154, June 20, pp. 1245–1252). A general account is given of the organization of the official Swiss research and testing institute, the Eidgenossische Materialprufüngs und Versuchsanstalt für Industrie, Bauwesen und Gewerke (E.M.P.A.). The work in progress on the mechanical properties of metals is indicated.—C. O.

**The Practical Training of Professional Electrical Engineers.** (Institution of Electrical Engineers, 1947, July, Pamphlet). This is the report of a joint committee appointed by the Council of the British Electrical and Allied Manufacturers' Association, the Radio Industry Council, and the Council of the Institution of Electrical Engineers, on the practical training of professional electrical engineers.—J. R.

**Training and Research for the Iron and Steel Industry.** (Iron and Coal Trades Review, 1947, vol. 154, May 2, pp. 793–795). Metallurgical research in progress at the University of Sheffield is discussed.—J. R.

**Scientists and Technologists.** A. B. Searle. (Iron and Steel, 1947, vol. 20, Apr., pp. 123–127). The functions and personal prospects of scientists and technologists engaged in the iron and steel industry are analysed and discussed.—J. R.

## BOOK NOTICES

BENEDICT, O. J., jun. "*Manual of Foundry and Pattern Shop Practice.*" 8vo, pp. x + 361. Illustrated. New York and London, 1947 : McGraw-Hill Book Co., Inc. (Price 16*s.* 6*d.*).

This volume deals with the fundamental processes of pattern design and construction, moulding, cupola operation, pouring, cleaning, and inspection of castings. —R. E.

GRIFFITHS, E. "*Methods of Measuring Temperature.*" Third Edition. Revised and Reset. 8vo, pp. x + 223. Illustrated. London, 1947 : Charles Griffin and Co., Ltd. (Price 20*s.*).

This volume is concerned with the measurement of temperature, whether in scientific investigations or in the control of industrial operations. It contains the following chapters : The Fundamental Scale of Temperature, The Mercury Thermometer, The Resistance Thermometer, The Thermocouple, The Fourth-Power Law of Radiation—Total Radiation Pyrometers; Total Radiation from Oxide and Metallic Surfaces ; Distribution of Energy in the Spectrum of a "Full Radiator "—Principles of Optical Pyrometry, Distribution of Energy in the Heat-Emission Spectrum of Metals ; High Temperature Melting Points and Boiling Points.—R. E.

HEPBURN, J. R. I. "*The Metallization of Plastics.*" Sm. 8vo, pp. 71. Illustrated. London, 1947 : Cleaver-Hume Press, Ltd. (Price 6*s.*).

This is a survey of existing information on the covering of plastic materials with a metallic deposit in order to modify their properties.—R. E.

HUGHES, T. P. "*Metals and Plastics. Production and Processing.*" 8vo, pp. xi + 373. Illustrated. Chicago, Ill. 1947 : Irwin-Farnham Publishing Co. (Price 24*s.* 9*d.*).

The underlying purpose of this volume is to present a comprehensive perspective of manufacturing processes with a detailed study of some of the more common metals, alloys and plastics so that the student will have an understanding of their fundamental potentialities and a basis for selection.

The first chapters deal with metals and their internal structures, equilibrium diagrams, and the physical properties of metals. These are designed to introduce the student to the basic structures of ferrous and non-ferrous metals and alloys, and their properties. Then follow chapters on the manufacture of iron, the production of steels, casting processes, the mechanical working of metals, non-ferrous metals and alloys, welding processes, the iron/iron-carbide equilibrium diagram and the heat-treatment of metals. The final chapter classifies the various steels according to the A.I.S.I. and S.A.E. systems.

The chapter on plastics classifies these materials and discusses their composition, the processes by which they are formed, and the engineering applications and properties of the various types of plastics. Glossaries of terms used in the text are furnished in the appendix.—R. E.

JOHNSON, C. G. "*Metallurgy.*" Third Edition. 8vo, pp. vii + 418. Illustrated. Chicago, 1946 : American Technical Society. (Price 35*s.*).

The third edition of this work has now made its appearance. The object is to present in a simple manner knowledge concerning the manufacture and behaviour of the many metals and alloys in present-day use. The text has been planned to serve merely as an introduction to the science of metallurgy.— —R. E.

JOST, W. "*Explosion and Combustion Processes in Gases.*" Translated by H. O. Croft. First Edition. 8vo, pp. xv + 621. Illustrated. New York and London, 1946 : McGraw-Hill Book Co., Inc. (Price 37*s.* 6d.).

This is a translation of the author's German work on jet propulsion. The book presents the experimental and theoretical facts underlying explosion and combustion processes in gases. It serves as an introduction to the field, and is also of great practical value to those doing research in the various allied fields. A broad theoretical basis, as well as a detailed description of recent experimental work are provided from which the physical chemist can form his own conclusions independently of the theories of the author. —R. E.

"*Resistance Welding Manual (Revised Edition).*" 8vo, pp. viii + 544. Illustrated. Philadelphia, Pa. : Resistance Welder Manufacturers' Association. (Price 16*s.* 6*d.*).

In general, the arrangement of this volume is intended to present, in order, the fundamentals of resistance welding, the nature of the different resistance-welding processes, the resistance-welding characteristics of various important metal groups and the manner in which these characteristics affect resistance-welding procedures, recommended practices for resistance welding, the mechanical and electrical characteristics of resistance-welding machines, inspection, testing and quality control, and recommendations for the proper maintenance of equipment.—R. E.

## NEW PUBLICATIONS

AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS. "*Blast-Furnace and Raw Materials Committee of the Iron and Steel Division. Proceedings, Volume 5, Chicago Meeting, Apr. 25–26, 1946.*" 8vo, pp. 100. Illustrated. New York : The Institute.

AMERICAN IRON AND STEEL INSTITUTE. Society of Automotive Engineers. Contributions to the Metallurgy of Steel. No. 11. "*Hardenability of Alloy Steels.*" 8vo, pp. 146. New York, 1947.

AMERICAN SOCIETY FOR METALS. "*Review of Metal Literature.*" Vol. 3, 1946. 8vo. pp. 311. Cleveland, Ohio : The Society. (Price $15.00).

ASSOCIAZIONE FRA I CONSTRUTTORI IN ACCIAIO ITALIANI. "*Costruire in Acciaio.*" 8vo, pp. 142. Illustrated. Milan, 1947.

BRITISH STANDARDS INSTITUTION. British Standard 1369 : 1947. "*Metal Lathing (Steel) for Plastering.*" 8vo, pp. 7. London : The Institution. (Price 1*s.*).

BRITISH STANDARDS INSTITUTION. British Standard 1374: 1947. "*Log-Sheets for Steam Boiler Plants.*" 8vo, pp. 13. London : The Institution. (Price 2*s.*).

BRITISH STANDARDS INSTITUTION. "*B.S.* 1387 : 1947. *Steel Tubes and Tubulars Suitable for Screwing to B.S.* 21 *Pipe Threads.*" 8vo., pp. 23. Illustrated. London, 1947 : The Institution. (Price 2*s.* 6*d.*).

BRITISH STANDARDS INSTITUTION. British Standard 1389: 1947. "*Hose Connections for Welding and Cutting Appliances.*" 8vo, pp. 8, Illustrated. London : The Institution (Price 2*s.*).

BRITISH STANDARDS INSTITUTION. British Standard 1393 : 1947. "*Reinforced Diamond Dies for Wire Drawing.*" 8vo, pp. 21. London : The Institution. (Price 2*s.* 6*d.*).

BRITTON, K. G. "*Electronic Developments.*" 8vo, pp. viii + 208. London, 1947 : George Newnes, Ltd. (Price 7*s.* 6*d.*).

CHARLOT G. and D. BEZIER. "*Méthodes modernes d'analyse quantitative minérale.*" 8vo, pp. 525. Paris : Masson et Cie.

COUNCIL OF IRONFOUNDRY ASSOCIATIONS. "*Cost Ascertainment Methods for the Ironfounding Industry.*" London : The Council. (Price £2 2*s.*).

DARCY M. "*Pour le Forgeron.*" 8vo, Tome I. "*Métaux et Alliages de forge. Outillage de Forgeron. Combustibles. Maréchalerie.*" Pp. vi + 141. Tome II. "*Aciers de constructions. Gros outillages de forgeage. Estampage. Forgeage pour pression. Fours industriel.*" Pp. vi + 124. Paris, 1946. Dunod.

DAVIES, O. L. "*Statistical Methods in Research and Production, with Special Reference to the Chemical Industry.*" London : Oliver and Boyd. (Price 28*s.*).

DAY, J. W. "*Modern Metal Production.*" With particular reference to Direct-Casting, and with Notes on Centrifugal Casting, Powder Metallurgy, Impact Extrusion, Immersion Casting, and the Prerefining of Molten Substances. 4to, pp. 122. Walsall, 1947 : New World Publications.

"*Engineering Index,* 1946." 4to, pp. xxvi + 1307. New York : Engineering Index Inc. (Price $51.12).

GILBERT, L. O. "*Phosphating.*" (Rock Island Arsenal Laboratory Report No. 45-1552). 8vo, pp. 133. Washington D.C. : Hobart Publishing Co. (Price $6.50).

GRAVES, H. B., jun. "*The Mineral Key.*" New York, N.Y. : McGraw-Hill Book Co., Inc. (Price $4).

GRIFFITHS, E. "*Methods of Measuring Temperatures.*" Third Edition, revised. London : Charles Griffin and Co., Ltd. (Price 20*s.*).

GUILLET, L. "*La France, pays de grands découvertes.*" 8vo, pp. 236. Illustrated. Paris : Presses universitaires de France. (Price 300 francs).

HEPBURN, J. R. I. "*The Metallization of Plastics.*" Pp. 71. London, 1947 : Cleaver-Hume Press, Ltd. (Price 6*s.*).

MAZZOLENI, F. "*Lezioni di Tecnologie dei Metalli. Part I. Metallografia Generale.*" 8vo, pp. 410. Illustrated. Naples : Casa Editrice Humus.

MERSEREAU, S. F. "*Materials of Industry.*" Fourth Edition. Revised by C. G. Reen and K. L. Holderman. 8vo, pp. 632. New York, N.Y. : McGraw-Hill Book Co., Inc. (Price $2.80).

MOORE, H. F. "*Textbook of the Materials of Engineering.*" Seventh Edition. 8vo, pp. 450. New York, N.Y. : McGraw-Hill Book Co., Inc. (Price $5).

NEDERLANDSE VEREINIGING VOOR LASTECHNIEK. "*Lassymposium* 3, 4 *en* 5 *Juni,* 1947. *Het Lassen in de Ketel en Apparatenbouw. Het oplassen van Slutvaste Lagen.*" F'scap, pp. 123. Illustrated. Haarlem : De Technische Uitgeverij H. Stam.

PALMGREN, A. "*Ball and Roller Bearing Engineering.*" Pp. 270. Philadelphia, Pa. : S. H. Burbank and Co.

PARSONS, R. H. "*A History of the Institution of Mechanical Engineers,* 1847–1947." Centenary Memorial Volume. 8vo, pp. xi + 299. Illustrated. London, 1947 : The Institution of Mechanical Engineers.

ROSTOVSTEV, S. T. "*Theory of Metallurgical Processes.*" Pp. 307. Moscow : State Scientific Publishing House for Ferrous and Non-ferrous Metallurgy. [In Russian].

SIMON, L. E. "*German Research in World War II. An Analysis of the Conduct of Research.*" 8vo, pp. xi + 218. New York, N.Y. 1947 : John Wiley and Sons, Inc. (Price $4).

SLATER, J. C. "*Electromagnetism.*" 8vo, pp. 300. New York, N.Y. : McGraw-Hill Book Co., Inc. (Price $3.50).

STECKZEN, B. "*Bofors Historia 1646–1946.*" Stockholm : Aktiebolaget Bofors. (Price 23 kronor).

SWANSEA AND DISTRICT METALLURGICAL SOCIETY : "*Electrodeposition of Tin in the Manufacture of Tinplate.*" By C. Frenkel, 8vo, pp. 23. Briton Ferry, 1947.

*Welding Encyclopedia. 12th Edition.* 8vo, pp. 1024. Illustrated. New York, N.Y. McGraw-Hill Book Co., Ltd. (Price $6.50).

"*Whitworth, Sir Joseph.*" By F. C. Lea. 8vo, pp. 31. London : Longmans, Green and Co. (Price 1*s.* 6*d.*).